Encyclopaedia Metropolitana

Second Division.

Applied Sciences.

52

" *The greatest and most important Literary Enterprise of the day.*"—Critic.

CABINET EDITION OF THE

Vol. III., price 3s., cloth lettered,

LOGIC. By the Most Rev. Richard Whately, D.D., Archbishop of Dub
The Original Edition, with Synopsis and Index by the Editor.

Vol. IV., price 3s. 6d., cloth lettered,

RHETORIC. By the Most Rev. Richard Whately, D.D., Archbishop
Dublin. The Original Edition, with Synopsis and Index by the Editor.

Vol. V., price 6s., cloth lettered,

HISTORY OF THE CHRISTIAN CHURCH in the First Century. By
Right Rev. Samuel Hinds, D.D., Bishop of Norwich, and the Rev. J. H. Newman,
Third Edition, Revised.
" Erudite research is here combined with independent thought."—*Scottish Guardian.*

Vol. VI., price 4s., cloth lettered,

POLITICAL ECONOMY. By Nassau William Senior, Esq., late Profe
of Political Economy in the University of Oxford. Third Edition.

Vol. VII., price 2s. 6d., cloth lettered,

HISTORY OF THE JEWS, from the time of Alexander the Great to the
struction of Jerusalem by Titus, A.M. 3595, B.C. 409 to A.D. 70. By the Venerable Archd
Hale, A.M., Master of the Charter-house. Fourth Edition.

Vol. VIII., price 6s., cloth lettered,

SACRED HISTORY AND BIOGRAPHY, from the Antediluvian Period t
Time of the Prophet Malachi, A.M. 1 to A.M. 3607, B.C. 397. Edited by the Rev. F. A.
D.D., LL.D.
" Pleasing and good, and worthy of general attention."—*United Presbyterian Magazine.*

Vol. IX., price 7s. 6d., cloth lettered,

HISTORY OF GREEK LITERATURE. By the Hon. Sir T. N. Talfo
D.C.L., the Right Rev. C. J. Blomfield, D.D., Bishop of London; R. Whitcombe, Esq.,
Trinity College, Cambridge; E. Pococke, Esq.; the Rev. J. B. Ottley, M.A.; and the
H. Thompson, M.A., St. John's College, Cambridge.
" Full of information, expressed in the choicest language."—*Athenæum.*

Vol. X., price 5s., cloth lettered,

MORAL AND METAPHYSICAL PHILOSOPHY. SYSTEMS OF PHIL
PHY ANTERIOR TO THE TIME OF CHRIST. By the Rev. F. D. Maurice, M.A.
Edition. Re-written.
" Complete and satisfactory."—*Literary Gazette.*

Vol. XI., price 5s., cloth lettered,

INTRODUCTION TO UNIVERSAL HISTORY—On the Uses of His
as a Study, and On the Separation of the Early Facts of History from Fabl
Sir John Stoddart, LL.D. Re-written.
" We cannot speak too highly in its praise."—*Literary Gazette.*

May, 1855.

IMPORTANT WORKS
In Science and General Literature,

PUBLISHED BY

RICHARD GRIFFIN AND COMPANY,

PUBLISHERS TO THE UNIVERSITY OF GLASGOW,

VIA · VERITAS · VITA

5 Warwick Square,
PATERNOSTER ROW,
LONDON.

Prince of Wales Buildings,
BUCHANAN-STREET,
GLASGOW.

Classified Index.

ABBOTT.—MORAL AND EDUCATIONAL WORKS:

Comprising the Young Christian, Teacher, Way to do Good, &c. 8vo, 5s. cloth.

AIRY.—CONTRIBUTIONS TO THE ENCYCLOPÆDIA METROPOLITANA:

viz. Trigonometry, Figure of the Earth, and Tides and Waves. One Volume, 4to, 10s. 6d. cloth.

AIRY.—TRIGONOMETRY.

A TREATISE ON TRIGONOMETRY. By G. B. AIRY, F.R.S., Astronomer Royal. New edition. Edited by Professor BLACKBURN. Crown 8vo, cloth, 2s. 6d.

ANCIENT HISTORY,

Comprising the Political, Social, and Literary Histories of ROME, GREECE, EGYPT, ASSYRIA, PERSIA, &c. &c. By ARNOLD, TALFOURD, RAMSAY, EADIE, RENOUARD, WHEWELL, &c., &c, 10 vols., crown 8vo, cloth, gilt, 4l. 4s.

ANECDOTES—LITERARY AND SCIENTIFIC.

CYCLOPÆDIA OF LITERARY AND SCIENTIFIC ANECDOTE. Edited by WM. KEDDIE, Esq., Sec. Glasgow Philos. Society. Cr. 8vo, 5s. cloth.

ANECDOTES—RELIGIOUS.

CYCLOPÆDIA OF RELIGIOUS ANECDOTE; A vast Collection of Facts, Narratives, and Examples, with Copious Index, and Introductory Essay by Rev. Dr. CHEEVER. To which is added a Complete Series of Scriptural Texts illustrated by the Anecdotes. 4th edition. Crown 8vo, 5s. cloth.

BALFOUR.—BOTANY;

An Introduction to the Study of the Structure, Physiology, and Classification of Plants By JOHN H. BALFOUR, M.D., F.R.S.E., Professor of Botany in the University of Edinburgh. Numerous Illustrations, Third Edition, revised and enlarged by J. W. WILLIAMS, M.D., Lecturer on Botany at the Original School of Medicine, Dublin. Crown 8vo, 10s. 6d. cloth.

BIOGRAPHY, CYCLOPÆDIA OF;

Containing a Complete Series of Original Memoirs of the most Remarkable Individuals of all Times and Nations. By ALISON, BREWSTER, BURTON, CREASY, EADIE, KNIGHT, NICHOL, SPALDING, WORNUM, and other Contributors. With 150 Illustrations of Birth-places, &c. &c. Post 8vo, 12s. 6d. cloth.

BOOK OF NATURE:

THE BOOK OF NATURE; a COMPREHENSIVE INTRODUCTION to the NATURAL and PHYSICAL SCIENCES. From the German of Professor SCHOEDLER, with numerous Additions, by HENRY MEDLOCK, F.C.S. Second edition, corrected and enlarged. With Copious Index, and 500 Engravings, post 8vo, cloth, 10s. 6d.

BOOK OF TRADES;

Or, Circle of the Useful Arts. Illustrated by Engravings and Woodcuts, Eleventh Edition, 16mo, 4s. 6d. cloth.

BRITISH ELOQUENCE:

THE LITERARY, POLITICAL, and SACRED ORATORY of the NINETEENTH CENTURY, in a series of foolcap 8vo volumes. 3s. 6d. each, cloth.

Literary Oratory.—Addresses at various Literary Institutions.

FIRST SERIES.—ALISON, BREWSTER, HERSCHELL, TALFOURD, LORD CARLISLE, LORD MAHON, &c. &c.

SECOND SERIES.—BROUGHAM, CAMPBELL, COBDEN, BULWER LYTTON, MACAULAY, MASSON, PEEL, PLAYFAIR, LORD JOHN RUSSELL, SIR JAMES STEPHEN, PRINCIPAL SCOTT, PROFESSOR WILSON.

Political Oratory.—FIRST SERIES.—The Great Speeches of the Great Statesmen from the Close of the War to the Passing of the Reform Bill.

BROUGHAM.—WORKS.

THE CRITICAL, HISTORICAL, AND MISCELLANEOUS WORKS OF HENRY, LORD BROUGHAM, F.R.S. Now first Collected under the direct care and superintendence of his Lordship, and publishing in post 8vo volumes, 5s. each, cloth.

Vol. 1.—Lives of Philosophers of the Time of George III.
2.—Lives of Men of Letters of the Time of George III.
3, 4, 5.—Historical Sketches of the Statesmen who flourished in the Reign of George III.

BRYCE.—UNIVERSAL GAZETTEER.

A CYCLOPÆDIA OF POLITICAL AND PHYSICAL GEOGRAPHY, with Pronunciation, and numerous Illustrations. By JAMES BRYCE, A.M., F.G.S. Post 8vo.

CAMPBELL.—BRITISH NAVAL HISTORY.

Lives of the British Admirals and Naval History of Great Britain from the Days of Cæsar to the Present Time. Fifth Edition, engravings, fcp. 8vo, 3s. 6d. cloth.

CHANNING.—THEOLOGICAL WORKS.

Complete in One Volume, post 8vo, 5s. cloth.

CHANNING.—LITERARY WORKS.

Complete in One Volume, post 8vo, 5s. cloth.

CHRONOLOGICAL TABLES. Crown 8vo, cloth, 1s. each.

BIBLICAL AND EARLY ORIENTAL HISTORY.
GREECE AND MACEDONIA.
ROME TO THE FALL OF THE WESTERN EMPIRE.

COLERIDGE.—METHOD.

Introductory Dissertation to the Encyclopædia Metropolitana on the Science of METHOD, with a Synopsis. By SAMUEL TAYLOR COLERIDGE. Crown 8vo, 2s. cl.

COX.—BIBLICAL ANTIQUITIES.

A MANUAL OF BIBLICAL ANTIQUITIES, OR ILLUSTRATIONS OF THE HOLY SCRIPTURES. By the Rev. F. A. Cox, D.D., LL.D. With Maps and nearly 200 Illustrations, crown 8vo, 7s. 6d. cloth.

COX.—SACRED HISTORY AND BIOGRAPHY,

From the Antediluvian Period to the Time of the Prophet Malachi. Edited by Rev. F. A. Cox, D.D., LL.D. Crown 8vo, 6s. cloth.

CRUDEN.—CONCORDANCE

To the Holy Scriptures. Condensed and Revised from the larger Work of Cruden. By Rev. Professor EADIE, D.D., LL.D. Thirteenth edition, 8vo, 5s. cloth.

CURIOSITIES OF BIOGRAPHY;

Or, MEMOIRS of EXTRAORDINARY CHARACTERS. By ROBERT MALCOLM. 100 Characteristic Cuts. Foolscap 8vo, 2s. 6d. cloth.

DALGAIRNS—COOKERY.

THE PRACTICE OF COOKERY ADAPTED TO THE BUSINESS OF EVERY-DAY LIFE. By MRS. DALGAIRNS. Thirteenth Edition, enlarged, foolscap 8vo, 4s. 6d. cloth.

DAVY.—AGRICULTURAL CHEMISTRY.

ELEMENTS OF AGRICULTURAL CHEMISTRY. By Sir H. DAVY, Bart, P.R.S., &c. New edition, Revised, by JOHN SHIER, A.M., LL.D. 8vo, 3s. 6d. cl.

DEWEY.—THEOLOGICAL WORKS.

Complete in One Volume, post 8vo, 5s. cloth.

D'ORSEY.—SPELLING BY DICTATION;

A Series of Progressive Exercises in English Orthography, Illustrated by 1500 Quotations. By Rev. A. J. D. D'ORSEY, High School, Glasgow. 18mo, 1s. cloth.

PROFESSOR EADIE'S WORKS.

ANALYTICAL CONCORDANCE to the Holy Scriptures, with the Text in full. Post 8vo.—*In Preparation.*

BIBLICAL CYCLOPÆDIA; or, Dictionary of Eastern Antiquities, Geography, Natural History, Sacred Annals and Biography, and Biblical Literature. With Maps and numerous Pictorial Illustrations. Fifth edition, revised, post 8vo, 7s. 6d. cloth.

COMMENTARY ON THE GREEK TEXT OF THE EPISTLE OF PAUL TO THE COLOSSIANS. 8vo.—*In Preparation.*

COMMENTARY ON THE GREEK TEXT OF THE EPISTLE OF PAUL TO THE EPHESIANS. 8vo, 14s., cloth.

CONDENSED CONCORDANCE to the Holy Scriptures on the basis of Cruden. Post 8vo, 5s. cloth.

DICTIONARY OF THE BIBLE, for the Use of Young Persons. With 120 Illustrations, third edition, 18mo, 2s. 6d. cloth, or 3s. 6d. cape morocco gilt.

DIVINE LOVE, a Series of Doctrinal, Practical, and Experimental Discourses. Foolscap 8vo, 5s. cloth.

EARLY ORIENTAL HISTORY; Comprising the History of Egypt, Assyria, Persia, Media, Phrygia, and Phœnicia. Numerous Illustrations, cr. 8vo, 8s. cl.

ENCYCLOPÆDIA METROPOLITANA, Original 4to Edition.

ASTRONOMY, by Barlow, Herschell, and Airy. 21 Plates. 14s.

EXPERIMENTAL SCIENCE, by Barlow, Lunn, Roget, and Harvey. 39 Plates. 1*l*. 1s.

FINE ARTS, by Narrien, Westmacott, Gwilt, &c. 55 Plates. 1*l*. 1s.

MANUFACTURES AND MACHINERY, by Barlow and Babbage. 87 Plates. 2*l*. 2s.

MATHEMATICS, by Airy, De Morgan, Hall, Moseley, Dr. Peacock, &c. 17 Plates. 1*l*. 1s.

MECHANICAL PHILOSOPHY, by Barlow and Herschell. 78 Plates. 1*l*. 11s. 6d.

MEDICAL SCIENCE, by South, Bowman, Williams, &c. 18 Plates. 14s.

MENTAL PHILOSOPHY, by Coleridge, Whately, Maurice, &c. 14s.

NATURAL HISTORY, by Edwards, Phillips, &c. 131 Plates. 1*l*. 15s.

USEFUL ARTS, by Don, Lowe, Senior, &c. 10 Plates. 14s.

ENCYCLOPÆDIA METROPOLITANA, NEW AND REVISED EDITION.

The Second Edition of the Encyclopædia Metropolitana will be handsomely printed in a Series of Cabinet Volumes, each containing a Complete Treatise, in crown 8vo. The work will be thoroughly revised, many new Treatises added, the Articles all provided with comprehensive Indexes, or Analytical Tables of Contents, and abundantly illustrated by Maps, Woodcuts, and Engravings.

Vol. 1.—METHOD.	S. T. Coleridge. 2s.
2.—UNIVERSAL GRAMMAR.	Sir John Stoddart. 5s.
3.—LOGIC.	Archbishop Whately. 3s.
4.—RHETORIC.	Archbishop Whately. 3s. 6d.
5.—EARLY CHRISTIANITY.	Bishop Hinds. 6s.
6.—POLITICAL ECONOMY.	Nassau W. Senior. 4s.
7.—HISTORY OF THE JEWS.	Archdeacon Hale. 2s. 6d.
8.—SACRED HISTORY AND BIOGRAPHY.	Dr. Cox. 6s.
9.—GREEK LITERATURE.	Sir T. N. Talfourd, &c. 7s. 6d.
10.—ANCIENT PHILOSOPHY.	Rev. F. D. Maurice. 5s.
11.—UNIVERSAL HISTORY.	Sir John Stoddart. 5s.
12.—ROMAN ANTIQUITIES.	Professor Ramsay. 8s. 6d.
13.—BOTANY.	Professor Balfour. 10s. 6d.
14.—ELECTRO-METALLURGY.	James Napier. 3s. 6d.
15.—EARLY HISTORY OF GREECE.	Sir T. N. Talfourd, &c. 9s.
16.—PHOTOGRAPHY.	Robert Hunt, F.R.S. 6s.
17.—VETERINARY ART.	W. C. Spooner. 3s.
18.—EARLY ORIENTAL HISTORY.	Professor Eadie. 8s.
19.—HISTORY OF THE ROMAN REPUBLIC.	Dr. Arnold, &c. 8s. 6d.
20.—BIBLICAL ANTIQUITIES.	Dr. Cox. 7s. 6d.
21.—METALLURGY.	J. A. Phillips, F.G.S. 12s. 6d.
22.—THE CHURCH IN THE SECOND AND THIRD CENTURIES.	Professor Jeremie. 4s.
23.—HISTORY OF GREECE & MACEDONIA.	Dean Lyall, &c. 8s.
24.—ROMAN LITERATURE.	Dr. Arnold, &c. 10s. 6d.
25.—HISTORY OF THE ROMAN EMPIRE.	Dr. Arnold, &c. 10s. 6d.
26.—DECLINE AND FALL OF ROME.	Bishop Russel, &c. 10s. 6d.
27.—GREEK AND ROMAN PHILOSOPHY.	Bishop of London, &c. 6s.
28.—PHILOSOPHY OF THE FIRST SIX CENTURIES.	Rev. F. D. Maurice. 3s. 6d.
29.—HISTORY OF THE OTTOMAN EMPIRE.	Col. Procter, &c. 7s. 6d.
30.—TRIGONOMETRY.	Professor Airy. 2s. 6d.
31.—OCCULT SCIENCES.	Rev. E. Smedley, &c. 6s.
32.—GEOLOGY.	Prof. Phillips. 12s. 6d.
33.—THE CHURCH FROM THE FOURTH TO THE TWELFTH CENTURY.	Rev. J. B. S. Carwithen, &c

ECCLESIASTICAL HISTORY.

FIRST DIVISION.—HISTORY OF THE CHRISTIAN CHURCH IN THE FIRST CENTURY. By Right Rev. SAMUEL HINDS, D.D., Bishop of Norwich, and Rev. J. H. NEWMAN, B.D. Crown 8vo, 6s. cloth.

SECOND DIVISION.—CHRISTIANITY IN THE MIDDLE AGES.

Part I.—THE CHRISTIAN CHURCH IN THE SECOND AND THIRD CENTURIES, by JAMES A. JEREMIE, D.D., Regius Professor of Divinity in the University of Cambridge. 4s., cloth.

Part II.—THE CHRISTIAN CHURCH FROM THE FOURTH TO THE TWELFTH CENTURY. By Rev. J. M. GUILDING, Rev. J. B. S. CARWITHEN, B.D., &c.

THIRD DIVISION.—THE RISE, ACCOMPLISHMENT, & CONSEQUENCES OF THE REFORMATION; being the History of the Church from the Thirteenth Century to the present time. By Right Reverend Dr. HAMPDEN, Bishop of Hereford, Rev. J. E. RIDDLE, M.A., &c. &c.

GREEK AND ROMAN PHILOSOPHY AND SCIENCE.

HISTORY OF GREEK AND ROMAN PHILOSOPHY AND SCIENCE. By the Rev. DR. BLOMFIELD, WILLIAM LOWNDES, Esq., M.A., Q.C., Rev. J. W. BLAKESLEY, M.A., ANDREW FINDLATER, A.M., Rev. Professor JEREMIE, Rev. Professor WHEWELL, and other Contributors. Crown 8vo, 6s. cloth.

GREECE.—HISTORY OF.

HISTORY OF GREECE from the Earliest Period to the absorption of Greece in the Roman Empire. By E. POCOCKE, Esq., Rev. J. B. OTTLEY, M.A., Sir THOMAS N. TALFOURD, D.C.L., the late J. T. RUTT, Esq., WILLIAM ROE LYALL, D.D., Rev. J. H. B. MOUNTAIN, D.D., Rev. G. C. RENOUARD, B.D., and others. Illustrated by numerous Wood Engravings. 2 vols. crown 8vo, 17s. cloth.

1. EARLY HISTORY OF GREECE. 150 Engravings, 9s. cloth.
2. HISTORY OF GREECE AND MACEDONIA. 100 Engravings, 8s. cloth.

GREEK LITERATURE.

A HISTORY OF GREEK LITERATURE. By Sir T. N. TALFOURD, Right Rev. Dr. BLOMFIELD, Bishop of London, Rev. H. THOMPSON, M.A., and other Contributors. With Chronological Tables and Index. Crown 8vo, 7s. 6d. cloth.

GRIFFIN'S PORTABLE CYCLOPÆDIAS.

A series of Alphabetical Reference Books adapted to the wants of the present age; beautifully printed and embellished. Post 8vo, cloth.

Vol. 1.—BIBLICAL KNOWLEDGE.	PROFESSOR EADIE. 7s. 6d.
2.—CHEMISTRY AND MINERALOGY.	DR. THOMSON. 12s. 6d.
3.—UNIVERSAL BIOGRAPHY.	ALISON, BREWSTER, &c. 12s. 6d
4.—UNIVERSAL HISTORY.	M'BURNEY and NEIL. 10s. 6d.
5.—ANALYTICAL CONCORDANCE TO THE BIBLE.	PROFESSOR EADIE.
6.—UNIVERSAL GAZETTEER.	JAMES BRYCE, F.G.S,

HALE.—HISTORY OF THE JEWS,

From the Time of Alexander the Great to the Destruction of Jerusalem by Titus. By Archdeacon HALE, Master of the Charter House. Crown 8vo, 2s. 6d. cloth.

HERSCHEL.—CONTRIBUTIONS TO THE ENCYCLOPÆDIA

METROPOLITANA: viz. Physical Astronomy, Light, and Sound. 4to, cloth, 15s.

HINDS.—EARLY CHRISTIANITY.

THE RISE AND EARLY PROGRESS OF CHRISTIANITY. By Right Rev. Dr. HINDS, Bishop of Norwich. New Edition, Revised, crown 8vo, 5s. cloth.

HORATII OPERA.

THE COMPLETE WORKS OF HORACE, from the Text of ORELLIUS, with 250 Illustrations from the most authentic sources, and Introductory Dissertation on the Life and Poetry of Horace, by the Rev. HENRY THOMPSON, M.A., late Scholar of Cambridge, Vicar of Chard. Crown 8vo, 7s. 6d. antique binding.

HUNT.—PHOTOGRAPHY.

Embracing the Daguerreotype, Calotype, and all the published Photographic processes. By ROBERT HUNT, F.R.S. Fourth edition, enlarged. Numerous Engravings, crown 8vo, 6s. cloth.

JAMIESON.—RELIGIOUS BIOGRAPHY.

POPULAR CYCLOPÆDIA OF MODERN RELIGIOUS BIOGRAPHY. By the Rev. ROBERT JAMIESON, D.D. Second Edition, crown 8vo, 5s., cloth.

JEREMIE.—CHURCH HISTORY.

HISTORY OF THE CHRISTIAN CHURCH IN THE SECOND AND THIRD CENTURIES. By JAMES AMIRAUX JEREMIE, D.D., Regius Professor of Divinity, Cambridge. Crown 8vo, 4s. cloth.

KERR.—MANUFACTURE OF SUGAR;

A Practical Treatise on the Cultivation of the Sugar Cane and the Manufacture of Sugar. By THOMAS KERR, of Barbadoes. Crown 8vo, 5s. cloth.

KINGSLEY.—NATIONAL SERMONS.

By the Rev. CHARLES KINGSLEY, Canon of Middleham, and Rector of Eversley, author of Yeast, Alton Locke, &c. First and Second Series, fcap. 8vo, each 5s. cl.

MANUFACTURES AND MACHINERY.

THE ENCYCLOPÆDIA OF ARTS, MANUFACTURES, AND MACHINERY By Professor BARLOW. With an Introductory Dissertation, by Professor BABBAGE. New edition, with 87 Pages of Engravings. 4to, 42s. half russia.

MATHEMATICS.

THE ENCYCLOPÆDIA OF PURE MATHEMATICS, comprehending a complete Course of Mathematical Science. By Professors AIRY, BARLOW, DE MORGAN, HALL, HAMILTON, LEVY, MOSELEY, Dr. LARDNER, F.R.S., and Rev. Dr. PEACOCK, Dean of Ely. With 17 Engravings, £1 1s. cloth.

MAURICE.—MORAL AND METAPHYSICAL PHILOSOPHY:

ANCIENT PHILOSOPHY, comprising the Hebrew, Egyptian, Hindoo, Chinese. Persian, Grecian, Roman and Alexandrian Systems of Philosophy. By Rev. F. D. MAURICE, M.A. Chaplain to Lincoln's Inn. Third Edition, cr. 8vo, 5s. cloth.

PHILOSOPHY OF THE FIRST SIX CENTURIES. Crown 8vo, 3s. 6d. cloth.

PHILOSOPHY OF THE MIDDLE AGES. Crown 8vo. *In the Press.*

MODERN PHILOSOPHY. Crown 8vo. *In the Press.*

MENTAL SCIENCE.

SAMUEL TAYLOR COLERIDGE ON METHOD; ARCHBISHOP WHATELY'S TREATISES ON LOGIC and RHETORIC. Crown 8vo, 5s. cloth.

MITCHISON.—SCOTTISH SONG.

A HAND-BOOK OF THE SONGS OF SCOTLAND, containing the best Songs of Burns, &c. Set to Music. With Notes, and Life of Wilson. By WILLIAM MITCHISON. Crown 8vo, 2s. 6d. cloth.

MORRISON.—BOOK-KEEPING;

A Complete System of Practical Book-keeping by Single Entry, Double Entry, and a New Method. By C. MORRISON. Eighth edition, 8vo., 8s. half-bound.

NAPIER.—ELECTRO-METALLURGY;

Containing an Account of the most Improved Methods of Depositing Copper, Silver, Gold, and other metals, with numerous Illustrations. By JAMES NAPIER, F.C.S. Second edition, revised and enlarged. Crown 8vo, 3s. 6d. cloth.

NAPIER.—DYEING.

A MANUAL OF DYEING, Practical and Theoretical. By JAMES NAPIER, F.C.S. With Engravings. Post 8vo, 7s. 6d. cloth.

NAPIER.—DYEING RECEIPTS.

A MANUAL OF DYEING RECEIPTS, with Specimens of Cloth. By JAMES NAPIER, F.C.S. Post 8vo, 7s. 6d. cloth.

NATURAL SCIENCES.

INTRODUCTORY MANUAL OF THE NATURAL SCIENCES, comprising Geology, Botany, and Zoology. By Professors SCHOEDLER and MEDLOCK. Numerous Illustrations, crown 8vo, 5s. cloth.

NICHOL.—PHYSICAL SCIENCES.

A CYCLOPÆDIA OF THE PHYSICAL SCIENCES, comprising Acoustics—Astronomy—Dynamics—Electricity—Heat—Hydrodynamics—Magnetism—Philosophy of Mathematics—Meteorology—Optics—Pneumatics—Statics. By J. P. NICHOL, LL.D., Professor of Astronomy in the University of Glasgow. With Numerous Illustrations. Post 8vo.

OTTOMAN EMPIRE.—HISTORY OF.

HISTORY OF THE OTTOMAN EMPIRE, including a Sketch of the Greek Empire and the Crusades. By Col. PROCTER, Rev. J. E. RIDDLE, and J. M'CONECHY. Cr. 8vo, 7s. 6d.

PHILLIPS.—METALLURGY;

A MANUAL OF METALLURGY: being an Account of Assaying, Mining, Smelting, &c., by J. A. PHILLIPS, F.C.S. Second Edition, revised and enlarged, with above 200 Engravings. Crown 8vo, 12s. 6d. cloth.

PHILLIPS.—GOLD MINING;

A POPULAR TREATISE on GOLD-MINING, and ASSAYING. By J. A. PHILLIPS, F.C.S., F.G.S. With Illustrations, second edit., fols. 8vo, 2s. 6d. cloth.

PHILLIPS.—GEOLOGY.

A MANUAL OF GEOLOGY, Practical and Theoretical, with Numerous Illustrations. By JOHN PHILLIPS, M.A., F.R.S., F.G.S., Deputy Reader of Geology in the University of Oxford. Crown 8vo. 12s. 6d.

PHYSICAL SCIENCES.

INTRODUCTORY MANUAL OF THE PHYSICAL SCIENCES, comprising Natural Philosophy, Astronomy, and Chemistry. By Professors SCHOEDLER and MEDLOCK. Numerous Illustrations, crown 8vo, cloth, 5s.

POCOCKE.—INDIA IN GREECE,

Or, TRUTH IN MYTHOLOGY, containing an Account of the Sources of the Hellenic Race, the Colonisation of Egypt and Palestine from India, the Wars of the Grand Lama, and the Bud'histic Propaganda in Greece. By E. POCOCKE, Esq. Illustrated by Numerous Maps of India and Greece, post 8vo, 12s. cloth.

POLSON.—PRINCIPLES OF THE LAW OF NATIONS,

With Practical Notes on the Law of Blockade, and on Contraband in War. By ARCHER POLSON, Esq., Lincoln's Inn. To which is added DIPLOMACY. By THOMAS HARTWELL HORNE, B.D. Crown 8vo, 3s. 6d. cloth.

POPE.—POETICAL WORKS.

COMPLETE POETICAL WORKS and TRANSLATIONS of ALEXANDER POPE. Portrait and Vignette. New Edition, 8vo, 5s. cloth.

POPULAR LIBRARY;

A Miscellany of Amusement and Instruction; numerous Engravings, 12mo, 3s. 6d. cl.

PROCTER—CRUSADES.

HISTORY OF THE CRUSADES; their Rise, Progress, and Results. By Colonel PROCTER. With Illustrations after Gilbert, &c. Crown 8vo, 5s. cloth.

RAMSAY.—ROMAN ANTIQUITIES;

A MANUAL OF ROMAN ANTIQUITIES. By WILLIAM RAMSAY, M.A., Professor of Humanity in the University of Glasgow. With Map, numerous Engravings, and very copious Index. Third edition, crown 8vo, 8s. 6d. cloth.

REID.—INTELLECTUAL POWERS.

ESSAYS ON THE INTELLECTUAL POWERS OF MAN. By THOMAS REID, D.D. New edition, crown 8vo, 5s.

RELIGIOUS DENOMINATIONS.

A CYCLOPÆDIA OF RELIGIOUS DENOMINATIONS. An Authentic Account of the various Religions prevailing throughout the World, written by Members of the respective Bodies. Second edition, crown 8vo, 5s. cloth.

ROME—HISTORY OF.

HISTORY OF ROME, from the Foundation of the City of Rome to the Extinction of the Western Empire. By Rev. THOMAS ARNOLD, D.D., the Rev. Professor JEREMIE, D.D., SIR THOMAS NOON TALFOURD, D.C.L., and others. Illustrated by numerous Engravings. Three Volumes, crown 8vo, cl. extra, £1 9s. 6d.

1. THE ROMAN REPUBLIC, 8s. 6d. cloth.
2. THE ROMAN EMPIRE, 10s. 6d. cloth.
3. THE DECLINE AND FALL OF THE ROMAN POWER, 10s. 6d. cloth.

ROMAN LITERATURE.

A HISTORY OF ROMAN LITERATURE. By Rev. THOMAS ARNOLD, D.D., Rev. HENRY THOMPSON, M.A., Rev. J. H. NEWMAN, B.D., the Rev. J. M. NEALE, M.A., and other Contributors. Crown 8vo, 10s. 6d. cloth.

SCHOEDLER AND MEDLOCK'S SCIENTIFIC TREATISES,

FOR SCHOOLS. New Editions, post 8vo, cloth.

ASTRONOMY. With 51 Engravings. 1s. 6d.
BOTANY. With 121 Engravings. 1s. 6d.
CHEMISTRY. With 50 Engravings. 2s.
MINERALOGY and GEOLOGY. With 128 Engravings. 1s. 6d.
NATURAL PHILOSOPHY. With 150 Engravings. 2s. 6d.
ZOOLOGY and PHYSIOLOGY. With 84 Engravings. 2s.

SCRIPTURE READINGS—JAMIESON.

THE BIBLE FAMILIARLY EXPLAINED TO THE YOUNG. Edited by the Rev. Dr. JAMIESON. With Illustrations, foolscap 8vo, 3s. 6d. cloth.

SENIOR.—POLITICAL ECONOMY;

The Science which Treats of the Nature, Production, and Distribution of Wealth. By NASSAU W. SENIOR, M.A. Third edition, crown 8vo, 4s. cloth.

SMEDLEY.—OCCULT SCIENCES.

THE OCCULT SCIENCES—SKETCHES OF THE TRADITIONS AND SUPERSTITIONS OF PAST TIMES AND THE MARVELS OF THE PRESENT DAY: comprising the Ancients and their Fables—Supernatural Beings—Localities—Exercise of Occult Power—Psychological Experiences—Wonders of Divination—Natural and Artificial Charms. By Rev. E. SMEDLEY, M.A., W. COOKE TAYLOR, LL.D., Rev. H. THOMPSON, M.A., and ELIHU RICH, Esq. Crown 8vo, 5s. cloth.

SPOONER.—VETERINARY ART.

A Practical Treatise on the Diseases of the Horse. By W. C. SPOONER, Esq. With 50 Engravings. Crown 8vo, 3s. cloth.

STODDART.—INTRODUCTION TO HISTORY;

Two Dissertations—FIRST: On the Uses of History as a Study. SECOND: On the Separation of the Early Facts of History from Fable. By Sir JOHN STODDART, LL.D. Crown 8vo, 5s. cloth.

STODDART.—UNIVERSAL GRAMMAR,

Or, the Pure Science of Language. By Sir JOHN STODDART, LL.D. Third edition, revised, crown 8vo, 5s. cloth.

THOMSON.—CHEMISTRY.

A CYCLOPÆDIA OF CHEMISTRY, PRACTICAL AND THEORETICAL, with its Applications to Mineralogy, Physiology, and the Arts. By R. D. THOMSON, M.D., F.R.S., F.C.S., Professor of Chemistry at St. Thomas's Hospital College, London. With numerous Illustrations, post 8vo, 12s. 6d. cloth.

UNIVERSAL HISTORY.

CYCLOPÆDIA OF UNIVERSAL HISTORY: comprising Tabular Views of Contemporaneous Events in all Ages, from the Earliest Records to the Present time, arranged Chronologically and Alphabetically. Edited by ISAIAH M'BURNEY, B.A., and SAMUEL NEIL, Esq. Post 8vo, 10s. 6d. cloth.

VIRGILII OPERA.

THE COMPLETE WORKS OF VIRGIL, from the text of Heyne and Wagner, with 300 Illustrations, from the most authentic sources, and Introductory Dissertation on the Life and Poetry of Virgil. By Rev. HENRY THOMPSON, M.A., late scholar of Cambridge, Vicar of Chard, &c. Crown 8vo, 8s. 6d., antique binding.

WHATELY.—LOGIC.

Original Edition, complete, forming part of the Encyclopædia Metropolitana. With Synopsis and Index. Crown 8vo, 2s. sewed, or 3s. cloth.

WHATELY.—RHETORIC.

Original Edition, complete, forming part of the Encyclopædia Metropolitana. With Synopsis and Index. Crown 8vo, 2s. 6d. sewed, or 3s. 6d. cloth.

WHITE.—THE NATURAL HISTORY OF SELBORNE.

THE NATURAL HISTORY OF SELBORNE. By Rev. GILBERT WHITE, A.M. New edition, greatly enlarged by Captain THOMAS BROWN, F.L.S., &c. With coloured Illustrations, foolscap 8vo, cloth, 3s. 6d., or richly gilt, 4s.

WITTICH.—PHYSICAL GEOGRAPHY.

CURIOSITIES OF PHYSICAL GEOGRAPHY. A Description of the most Remarkable Natural Phenomena. By WILLIAM WITTICH. New edition. Small 8vo, 2s. 6d. cloth.

WOLFE.—MESSIANIC PROPHECIES.

THE MESSIAH, as PREDICTED in the PENTATEUCH and PSALMS; being a new Translation and Critical Exposition of these Sacred Oracles. By J. R. WOLFE, author of the "Practical Hebrew Grammar." 8vo. 10s. 6d. cloth.

ZOOLOGY—ILLUSTRATIONS OF.

A Series of Ninety Engravings, comprehending about a Thousand Figures of Quadrupeds, Birds, Fish, Reptiles, Mollusca, Insects, Crustacea, Polyps, &c., engraved by J. W. Lowry and Thomas Landseer, after Sowerby, Charles Landseer, and others. The Descriptions by JOHN FLINT SOUTH, Esq., F.L.S., J. E. GRAY, Esq., F.L.S., J. F. STEPHENS, Esq., F.L.S., F.Z.S., and others. Im. 4to, 31s. 6d. cl. gt.

Cabinet Edition of the Encyclopædia Metropolitana—continued.

Vol. XII., price 8s. 6d., cloth lettered,

ROMAN ANTIQUITIES. By WILLIAM RAMSAY, M.A., Professor of Humanity in the University of Glasgow. With Map, and One Hundred and Thirty Illustrations. Third Edition.

"Comprises all the results of modern improved scholarship within a moderate compass."—*Athenæum.*

Vol. XIII., price 10s. 6d., cloth lettered,

BOTANY. By JOHN HUTTON BALFOUR, M.D., F.L.S., F.R.S.E., Professor of Botany in the University of Edinburgh. Third Edition, revised and enlarged by JOSEPH WILLIAMS, M.D., Lecturer on Botany at the original School of Medicine, Dublin. Numerous Engravings.

"Perhaps the most masterly digest of the science which has yet appeared."—*Witness.*

Vol. XIV., price 3s. 6d., cloth lettered,

ELECTRO-METALLURGY: Containing an Account of the most Improved Methods of Depositing Copper, Silver, Gold, and other Metals. Second Edition, with Numerous Illustrations. By JAMES NAPIER, F.C.S.

"With this book at hand, we don't think it possible to fail in obtaining satisfactory results."—*Art Journal.*

Vol. XV., price 9s., cloth lettered,

HISTORY OF GREECE from the Earliest Times to the Close of the Peloponnesian War. By E. POCOCKE, Esq.; Sir T. N. TALFOURD, D.C.L.; Rev. J. B. OTTLEY, A.M.; and the late J. T. RUTT, Esq. With upwards of One Hundred Engravings, from the most authentic sources.

"Altogether a gem."—*Glasgow Citizen.*

Vol. XVI., price 6s., cloth lettered,

PHOTOGRAPHY. By ROBERT HUNT, F.R.S., Professor of Physical Science in the Metropolitan School of Science, London. Fourth Edition, Numerous Engravings.

"Must prove of infinite service to those engaged in the pursuit of this entertaining science."—*Art Journal.*

Vol. XVII., price 3s., cloth lettered,

VETERINARY ART: A Practical Treatise on the Diseases of the Horse. By W. C. SPOONER, Esq., with 50 Engravings.

Vol. XVIII., price 8s., cloth lettered,

EARLY ORIENTAL HISTORY, comprising the History of the Egyptians, Assyrians, Phœnicians, Persians, &c. By the Rev. Professor EADIE, D.D., LL.D. With Numerous Illustrations.

"In all respects a thoroughly good book."—*Dr. Kitto.*

Vol. XIX., price 8s. 6d., cloth lettered,

HISTORY OF THE ROMAN REPUBLIC. By the Rev. THOS. ARNOLD, D.D., late Head Master, Rugby School; Sir THOS. N. TALFOURD, D.C.L.; the Rev. Professor JEREMIE, and others. With Numerous Illustrations.

Vol. XX., price 7s. 6d., cloth lettered,

BIBLICAL ANTIQUITIES AND GEOGRAPHY, including the Language, Geography, and Early History of Palestine. Edited by the Rev. F. A. COX, D.D., LL.D. With Maps and Numerous Illustrations.

"The most readable book on the subject in our language."—*Baptist Magazine.*

Vol. XXI., price 12s. 6d., cloth lettered,

METALLURGY. A Practical Treatise on the Chemistry of the Metals. By JOHN ARTHUR PHILLIPS, Esq., F.C.S. Second Edition, revised. Illustrated by nearly 200 Engravings.

"A *sine qua non* to every metallurgist."—*Mining Journal.*

Vol. XXII., price 4s., cloth lettered,

HISTORY OF THE CHRISTIAN CHURCH in the Second and Third Centuries. By JAMES AMIRAUX JEREMIE, D.D., Regius Professor of Divinity, Cambridge.

"It is an admirable text-book."—*Evangelical Magazine.*

Vol. XXIII., price 8s., cloth lettered,

HISTORY OF GREECE AND MACEDONIA, from the Age of Xenophon to the absorption of Greece in the Roman Empire, including the History of Alexander the Great and his Successors. By Dr. LYALL, Dean of Canterbury, Rev. G. C. RENOUARD, B.D., &c. &c. With Numerous Illustrations.

"The dissertations are full, luminous, and charmingly written."—*Eclectic Review.*

Vol. XXIV., price 10s. 6d., cloth lettered,

HISTORY OF ROMAN LITERATURE. By the Rev. THOS. ARNOLD, D.D., late Head Master, Rugby School; Rev. HENRY THOMPSON, M.A.; Rev. Dr. NEWMAN; Rev. J. B. OTTLEY, M.A.; and Rev. J. M. NEALE, Warden of Sackville College.

ENCYCLOPÆDIA METROPOLITANA:

OR

SYSTEM OF UNIVERSAL KNOWLEDGE.

ON A METHODICAL PLAN

PROJECTED BY SAMUEL TAYLOR COLERIDGE.

CABINET EDITION.

GEOLOGY.

GLASGOW:
PRINTED BY BELL AND BAIN.

PREFACE.

WHOEVER shall review, after a quarter of a century,* the work in which he had recorded the results of careful study, will experience an interest of no common description. Thus contemplating from a distance, with a calm and critical glance, his own former thoughts and opinions, he will obtain a measure of the progress of his own mind, a scale by which to calculate the growth of his own branch of knowledge. He will learn in what degree science has changed its aspect; to what extent old interpretations have been confirmed by additional experience, or corrected by new discoveries. He will be gratified by finding that much of what was thought true can still be defended as truth, and fortified by new illustrations; he will deal justly with the errors which he finds in his old performance, in the hope that others may deal gently with the mistakes which, doubtless, will be detected in the new expression of opinion.

Since the first appearance of this Essay, Sedgwick and Murchison have successfully encountered the difficulties which arrested Smith and every earlier geologist on the limit of the older fossiliferous strata: they have, in truth, *discovered* the Cambrian and Silurian systems, and given us a wide and magnificent field of ancient strata and palæozoic life.† The Permian system has been defined in

* The treatise was begun in 1829-30, and was published in the Encyclopædia Metropolitana, in combination with an Essay on Volcanoes, by Dr. Daubeny.

† Murchison, Silurian System, 1837. Siluria, 1854. Geol. Proceedings, *passim*. Sedgwick, Geol. Proceedings, *passim*, and Palæozoic Fossils (in progress).

Russia,* the Siluro-Cambrian strata investigated in America,† the Green Sand group accurately explored in England,‡ the Marino-lacustrine beds of the Isle of Wight analyzed again and more completely,§ the Pleistocene deposits invested with an accurate meaning.||

The labours of Griffith, Portlock, Oldham, Hamilton, Jukes, and M'Coy have made the structure of Ireland familiar to us. Scotland, long since explored by Jameson and MacCulloch, and described by Boué and Necker, has been put in relation with English geology by Sedgwick, Murchison, Miller, Milne, Smith, Sharpe, and Forbes. De la Beche, having succeeded in organizing a general survey of the British islands, has with his fellow-labourers, Forbes, Ramsay, and Salter, prepared admirable maps and memoirs of authority, and inimitable decads of organic remains. Lyell continually enriches the science which owes him so much. The impulse long since given by Buckland and Conybeare is still felt among us. Ansted, Austen, Bell, Brodie, Bunbury, Charlesworth, Milne Edwards, Darwin, Davidson, Egerton, Edwards, Fitton, Horner, Jones, King, Lloyd, Lonsdale, Morris, Owen, Prestwich, Wood, Woodward, Wright, and a multitude of other observers, are daily adding to our store of Palæontology and topographical geology. The Palæontographical Society, guided by Bowerbank, has already earned enduring gratitude by the magnificent memoirs which it has produced on corals, brachiopoda, chelonida, saurians, the crag, and other matchless labours.

This and much more has been done by our countrymen, and by those eminent foreign geologists who now fill every corner of the world with records of their accurate labours; so that we are approaching the day when even that amazing result of united labour,

* By Murchison.
† By Hall, Rogers, and Dale Owen.
‡ By Fitton.
§ By the lamented E. Forbes.
|| Smith, Trimmer, &c.

A GEOLOGICAL MAP OF THE GLOBE, is to be included among things accomplished. Yet, amidst all this activity of research, this universal sound of the hammer, the *principles of Geology* are unaltered; the methods of research and the lines of reasoning remain the same; the great laws of phenomena which were accepted in 1830 are still immovable; the great questions then proposed are still waiting for complete solution. We have *advanced* in the same paths, and made further conquests by the use of the same arms, and shall continue to do so; because the way and the weapons are indicated by that true and modest philosophy which alone finds access to the secrets of nature:—

> Nec tellus obstat, quin omnia despiciantur,
> Sub pedibus quæquomque infra per inane geruntur.

We have, indeed, lost some of those leaders whose names are on every tongue. Smith, the "father of English Geology," has gone to his long rest, followed very lately by Jameson, Greenough, and De la Beche. We have lost Mantell, the spirited explorer of the Wealden; but his Iguanodon still survives in his own admirable works and in the pages of Owen, and has grown up under the plastic hand of Hawkins, a worthy type of the "Age of Reptiles." We have mourned over Strickland—

> —— quem, non virtutis egentem,
> Abstulit atra dies ——.

and our sorrow has been renewed over the early grave of Edward Forbes.

The Treatise now offered to the public has been enlarged rather than changed; repaired with new materials, but not built on a new model. It was indeed necessary to reconstruct all that related to the Palæozoic strata, but moderate additions and substitutions were sufficient for most other parts of the Work.

The former Edition contained a full and carefully arranged list of organic remains, both British and foreign, a catalogue such as is now rarely attempted even in separate works expressly devoted to Palæontology, like Morris's excellent volume on "British Fossils." Instead of attempting to rival this remarkable *census* of our extinct fauna and flora, I have arranged a sort of index to it in each principal group of strata, and am happy in thus calling attention to one of the most useful of English books. The large number of figures of organic remains which appear in this Volume* will at least inform the student of many characteristic genera and species. If it be practicable, the Work so long since promised †—an Introduction to Organic Remains—shall now be proceeded with, and be published in conformity with the present Volume.

* Excepting some cuts borrowed from Beudant's Elementary Treatise, the representations of fossils are furnished by the author.

† In 1834, when it was actually begun.

OXFORD, *July* 1, 1855.

CONTENTS.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

GEOLOGY.

CHAPTER I.

PROGRESS OF THE SCIENCE.

Objects and Scope of Geology.—The term science, as now employed, is understood to express, not only the body of information collected, general laws established, or system recognized in any department of human knowledge, but also the ultimate objects and whole scope of the research. Strictly speaking, perhaps, the former is its legitimate meaning. Thus the science of optics or of acoustics properly signifies the body of information acquired and the generalizations established in those branches of human study, but is popularly understood, by way of anticipation, to include indefinitely the expected or possible future accessions of knowledge on the subject.

It is in conformity with this ordinary language that we shall endeavour to give the definition of geology; for though truly none of the sciences of observation has made more remarkable progress toward successful generalization than this, yet the prospect of further discovery is so much richer than the retrospect, and the activity and talent employed in the research is so much on the increase, that we can hardly offer too bold and expanded an expression for the ultimate aims of geology.

It might provoke a smile to recount the singularly contracted notions on this subject which have till lately figured in works on geology. The history of the deluge, the discussion of the character and repositories of minerals, the classification of fossils, the effects and causes of volcanoes, belong indeed to this comprehensive subject, but these and many other important inquiries are only particular branches of the great study of geology.

One cause of the inadequacy of the definitions usually presented—probably not confined in its application to any one of the sciences of observation—is the difficulty of foreseeing, in the early stages of a new study, the direction and extent of its future development. Mathe-

matical science, founded upon the pervading idea of relative magnitude, may by this comprehensive definition, anticipate all the various determinations concerning number, proportion, and direction, which are daily added to its stores, and which are, in fact, the developments of recognized fundamental axioms; but the natural sciences have a different mode of unfolding themselves, and it is only after they have made great progress, and many detached inferences, drawn from still more scattered data, have been combined into system, that the most able cultivators can clearly discern whereto their labours eventually tend.

Definition.—Guided by these views, we shall define geology as that science to which it is allotted to investigate the ancient natural history of the earth; to determine by observation what phenomena of living beings or inorganic matter were formerly occasioned on or within the globe, in what order and under what conditions; to employ the comparative data, which are furnished by investigation of the present operations of nature, in characterizing and measuring the successive revolutions which the earth has undergone before arriving at its present state; and thus, finally, to furnish a complete historical view of the conditions which have regulated, and of those which do regulate, its system of mechanical, chemical, and vital phenomena.

From the terms of this definition we may at once understand why, in former times, the most able men erred so grievously in their attempts to elucidate the history of our globe; for, while geography was imperfectly known, before commerce and the knowledge of languages had made us acquainted with the productions and traditions of every clime, before the birth of most branches of physical science, it was impossible to accumulate the numerous and exact data from which alone geology takes its origin. And since the general truths of geology are made apparent only by the application of the known laws of modern nature, it is evident that, before the discovery and establishment of those laws, the wisest of the old philosophers had nothing to substitute for enlightened theory but arbitrary hypothesis and fanciful conjecture. These are the reasons why the ancient doctrines concerning the world are almost without exception bewildered with the impossible problem of the creation of matter, and buried in a chaos of subtle inventions.

Speculative Geology.—Cosmogony, not geology, is the subject of the old traditions of Phœnicia, Chaldæa, Egypt, and China; and the same incurable fault springs up again and again among every people, in every period, always with the same injurious effect. The modern fictions are not better or more probable than the old; none more remarkable than the cosmogony of the Babylonians which caught the attention of Niebuhr. According to it, the world began with a chaotic darkness, which was a fluid, and inhabited by swimming ani-

mals, of the strangest forms. Representations of them are said to have been preserved in the temple of Belus. When light appeared these animals hardened and died.

Ingenious Greece added a considerable refinement in the nature of the fictions by which it was sought on vague analogies to supply the want of fair inductions. The Epicurean doctrine of atoms, and the primary elements of Aristotle and Pythagoras, are inventions of a different order from the Egyptian "Egg of the World," and the primeval monsters of Chaldæa. Familiar with countries in which earthquakes were frequent, and volcanic eruptions not unknown, they quickly gathered right though vague impressions of great revolutions in nature, indulged the ideas of frequent changes in the relative extent of land and sea, and supported this doctrine by reference to historical facts concerning subsidence and elevation of land, to the occurrence of marine shells far from the sea, and to the ordinary processes of change, decay, and renewal in physical phenomena.

What Herodotus says regarding the sediments deposited by the Nile in the valley of Egypt, and carried out to sea; of the time (10,000 or 20,000 years) which he estimates as sufficient for the Nile, if diverted into the Erythræan sea, to fill up that long gulf;* and of the shells found on the hilly borders of Egypt which testified to its former submersion beneath the sea, may be quoted with approbation as a fair specimen of ancient observation and inference.†

In the pages of Aristotle such local truths assume the more imposing aspect of general propositions, involving frequent displacements of land and sea, periodical revolutions, and systematic changes at every point, but still preserving a constant sum of natural powers and effects.‡ These were also Pythagorean ideas,§ they were the basis of the system of Epicurus,‖ and in some form or other they are always recurring; the natural fruits of analogical reasoning:—

———————Sic rerum summa novatur
Semper.

In precise appreciation of the phenomena, the geographer Strabo appears to have far outstripped his predecessors; he distinctly alludes to the various explanations of the phenomena of marine remains, proposed by Eratosthenes, Xanthus, and Strato, and adds his own view of the matter, in terms not very different from those employed at the present day by the advocates of the gradual elevation of our solid land from the bed of the sea.

The ten centuries of war and commotion which succeeded the

* Her. ii. 11.—*εγω μεν ελπομαι γε και μυριων εντος χωσθῆναι αν* ———

† Her. ii. 12.—*ιδων τε την Αιγυπτον προκειμενην της εχομενης γῆς, κογχυλιαι τε φαινομενα επι τοισι ουρεσι.* The shells were, perhaps, truly "fossil," and belonged to the rocks in the hilly ground.

‡ Aristotle, Meteorologica.

§ Ovid, Metam. XV. expounds the system of Pythagoras as it was understood at Rome.

‖ Lucretius unfolds the philosophy of Epicurus with the zeal of a disciple and the grace of a poet.

destruction of the Western empire, were less favourable to the growth of physical science than even those which had preceded; and while all the learning of the world was shut up in cloisters, and confined to one class of society, we cannot wonder that the grand cosmogonies of the ancients should have dwindled into puerile discussions. Learning was in chains, but it was nevertheless spread abroad through Christendom, and waited but for the extension of geography and commerce, by the maritime discovery of India and America, to be emancipated from its thraldom; and for the discovery of the art of printing to be excited to energy and enthusiasm, by the physical and astronomical discoveries of Kepler and Galileo.

It was not, indeed, till the inductive philosophy, budding in Galileo, blossoming in Bacon, and rich with fruit in Newton, had been widely disseminated among mankind, that we were entitled to look for fixed data and limited generalizations in any branch of natural science. The diffusion of this mode of philosophizing may be said to have withdrawn the veil of prejudice which had previously obscured the visible creation, and to have really generated the sciences which treat of the properties of matter and the phenomena of life.

Origin of Inductive Geology.—Four different classes of phenomena have conducted men of observation to a partial acquaintance with the stratification of the crust of the earth.

1. The effects of disturbance in countries shaken by earthquakes and marked by periodical volcanic excitement—as Asia Minor, Italy.

2. The arrangement of the various soils in England.

3. The appearances of regular structure in the mines of Germany, Sweden, &c.

4. The remains of plants and animals entombed in the strata of England, France, Switzerland, Germany, Italy.

1. Of the first class of observers, the most distinguished in early times is Strabo, who gives an interesting account of the Katakekaumene, (burnt district), in the valley of the Hermus, in Asia Minor, a district which remained almost unvisited till Mr. Hamilton renewed our acquaintance with its remarkable features, so similar to those of Auvergne. The great cone of Etna caught the attention of the Greek philosophers and poets—the deep-seated source of its fires—their origin and decay. For this great mountain neither—

Ignea semper erit, neque enim fuit ignea semper.

And the phenomena connected with Vesuvius, which fatally stimulated the curiosity of the elder Pliny, have trained up in modern times philosophic men like Steno* and Lazzaro Moro,† who not only perceived succession of time in the deposition of the strata, but great physical changes—displacements of land and sea—affecting large

* De solido intra solidum, &c., 1669.

† De Crostacei, &c., 1740.

areas of country. It is in this school that we find the germs of our modern theories of elevation and depression of land, whether by the united and sudden violence of excited heat, or the gradual effort depending on a general change of dimensions or temperature of the globe—this being the Leibnitzian theory.*

2. **Agriculture.**—The early advancement of agriculture in a country so populous, and of so diversified an aspect as England, necessarily produced a very intimate knowledge of different soils; and as these depend on the nature of the substances beneath, which range in regular courses, it is not surprising that maps of the soil should have been early proposed by agriculturists. Dr. Lister, residing in Yorkshire, where the ranges of soil are very well defined, was the first to propose to the Royal Society, in 1683, a map of the soils of England.

"We shall be better able," he says, "to judge of the formation of the earth, when we have duly examined it, as far as human art can possibly reach, beginning from the outside downwards. And for this purpose, it were advisable that a soil or mineral map, as I may call it, were devised. The soil might either be coloured by a variety of lines or etchings; but great care must be taken very exactly to note on the map where such and such soils are bounded. As for example, in Yorkshire, the *woolds*, (wolds,) chalk, flint, and pyrites, &c. 2. *Blackmoor*, moors, sandstone, &c. 3. *Holderness*, boggy turf, clay, sand, &c. 4. *Western mountains*, moors, sandstone, coal, ironstone, clay, sand, &c. *Nottinghamshire*, mostly gravel, pebble, clay, sandstone, hall-plaster, or gypsum, &c. Now if it were noted how far these extended, and the limits of each soil appeared on a map, something more might be comprehended from the whole and from every part, than I can possibly foresee, which would make such a labour very well worth the pains. For I am of opinion such upper soils, if natural, infallibly produce such under minerals, and for the most part in such order. But I leave this to the industry of future times."

This scheme was partly executed by the county reports presented to the Board of Agriculture, the earliest of which dates from 1794; but the investigation being usually unconnected with sound views of the interior conformation of the earth, few of these detached efforts led to any important results. Packe, in his *Chorographical Chart of East Kent*, (1743), has shown what admirable general views of the physical geography and leading rocks of a district may be entertained, without that combination of results which leads to geology.

3. **Mining.**—Miners in every period must have been acquainted with the order of succession of the rocks through which they seek the treasures of coal and metal; and in a tract consisting of alter-

* Protogæa, 1680.

nating coal-seams, limestones, sandstones, and shales, as at Aldstone Moor, in Cumberland, the range and extent of the different strata must always have been familar to the workmen.

There must therefore always have been a MINERALOGICAL SCHOOL OF GEOLOGY in every country in which rich subterranean treasures attracted the attention of mankind.

Agricola embodied the floating information of the miners of Saxony as early as 1546; (*De Naturâ Fossilium;*) he was followed by Cordas, Gesner, Kentmann, Fabricius, Encelius, "not unworthy of praise," as we are told by Baier, (*Oryctographia Norica,*) 1708. Sweden, equally celebrated for its mines, produced, between 1730 and 1762, five complete systems of mineralogy, including the methods of Linnæus, Wallerius, Swab, and Cronstedt. Linnæus* makes known the series of strata in a part of Sweden; the passage is remarkable:—

1 infimum..........................*e* Cote.
2 secundum..........................*e* Schisto.
3 tertium..........................*e* Marmore, nidulantibus petrificatis pelagicis sæpe etiamnum peregrinis.
4 quartum..........................*e* Schisto.
5 supremum..........................*e* Saxo rupestri, sæpe vastissimo.

Compare with this the well-known sequence of Swedish Lower Silurian strata in the Kinnekulle, as given by Murchison in his latest work:† there is no difference:—

a (1) Lowest or fucoid Sandstone.
b (2) Alum slates.
c (3) Orthoceratite Limestone.
d (4) Black graptolite Schists.
e (5) Eruptive Greenstone.

Those works are principally devoted to a description of the most prominent minerals, and it is only incidentally that we gain from them proofs of the considerable, though detached information which the authors really possessed concerning the manner in which minerals constitute, by their assemblage, the crust of the earth.

In 1750, however, Tylas, a Swede, and in 1756, Lehmann, a German, broke through the fetters of a mere mineralogical method, and by proving a regular order of superposition among stratified rocks, opened the way to the sagacious generalizations of Werner and the cautious inductions of Saussure.

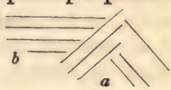
Werner.—A peculiar set of opinions concerning the formation of the earth, has been honoured by the title of the Wernerian theory; and the pupils of Werner who had found proof of the truth of his practical rules and inferences, may be readily pardoned for the deter-

* *Systema Naturæ. Regnum lapideum,* 1770.

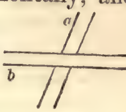
† Siluria, p. 318.

mination which they have shown to uphold the hypothetical notions of their master. But if we wish to ascertain the real value of the benefits which the researches of Werner have conferred upon geology, we must forget his theory, and view only the data which he collected for its foundation.

Werner was educated amidst the mines, and in the society of the most eminent mineralogists of Saxony; their experience and their opinions became his own, and doubtless swayed and directed the energies of his mind. To judge from his own works, and from the course which his pupils have so long pursued, the principal point of view under which Werner contemplated the rocks and metallic veins of Germany, was the relative period of their production. Lehmann had, indeed, taken the same course, and already distinguished primary and secondary rocks, the former (*a*) existing in mountain chains, mostly stratified at high angles of declination, and devoid of organic remains, the latter (*b*) disposed more horizontally, and stored with the reliquiæ of life. But Werner, with characteristic tact and boldness, applied this method of investigation to every case, and took it as the basis of his classification of rocks.



1

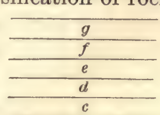


2

Basis of his System.—"When two veins (*a b*) cross, and one of them (*b*) cuts through the other, (*a*,) the one which is divided (*a*) is the more ancient."

Among stratified rocks superimposed on one another, the lower members of the series, those which lie nearest the centre of the earth, were deposited first, and the relative antiquity of the different strata is exactly in the order of their position. Thus *c* is the oldest rock of the series, *c*, *d*, *e*, *f*, *g*.

By this manner of proceeding in the instance of the Harz mountains, Werner was enabled to frame a system or classification of rocks in the order of their respective position as far as could then be ascertained, and consequently in the order of their consecutive formation. Thus the Brocken Mountain was described by Werner and his followers as a central cone of granite, upon which on all sides round were laid various other rocks in a certain and constant order of succession; as granite, clay-slate, limestone, greywacke and greywacke-slate, old red sandstone, limestones, gypsums, sandstones and limestones; the upper and newer strata having their outgoing or terminal edges lower and lower continually.



3

Werner presumed that this order of succession among these rocks would be found to prevail in all parts of the world, and thus announced a grand principle in the construction of the earth which was destined to have a most beneficial effect on geological theory and

observation. For, on the one hand, it dissipated the chaotic dreams of those who maintained that the whole crust of the earth was to be viewed as a mass of sediment from the waters of "the deluge;" and on the other, exhibited the most important subject of inquiry respecting the constitution of the earth, and fixed a precise method of investigating it.

Extending his views through other parts of Germany, Werner completed the following system of successive formations. (*Jameson*).

Werner's Series of Formations.—The lowest and oldest series of rocks discoverable by examination is supposed to be of crystalline origin, to be devoid of organic remains, and to have been originally, as at present, stratified at high angles of inclination. These are called by Werner—

Primitive Rocks.

Such are:—

Granite,	Porphyry,
Gneiss,	Syenite,
Micaceous schistus,	Topaz rock,
Argillaceous schistus,	Quartz rock,
Primitive limestone,	Primitive flinty slate,
Primitive trap,	Primitive gypsum,
Serpentine,	Eurite, or whitestone.

A second series of rocks appearing to be partly of crystalline and partly of mechanical origin, containing some remains of plants and animals, with slopes of stratification less remarkable than the former, is named by Werner, on account of these intermediate characters,—

Transition Rocks.

Transition limestone,	Greywacke,
Transition trap,	Transition flinty slate.

The third series consists of strata more decidedly of mechanical aggregation with abundance of organic exuviæ, and from the greater frequency of these strata in the flatter regions of the globe, where their planes of stratification are nearly level, they are called

Flœtz (*flat lying*) *Rocks.*

1st or old red sandstone.	3d sandstone, or quadersandstein.
1st flœtz limestone.	3d limestone, or planerkalkstein.
1st flœtz gypsum.	Flœtz trap.
2d variegated sandstone.	Independent coal formation.
2d flœtz gypsum.	Newest flœtz trap.
2d flœtz limestone, or muschelkalkstein.	

Lastly, various sandy and argillaceous strata, imperfectly known to Werner, but since ascertained to contain the whole vast series of tertiary strata, are included by him under the title of alluvial deposits.

That this classification is partly erroneous in principle, and in all

respects incomplete and inadequate to the rigour of modern investigation, is apparent at a first glance, but it obviously contains the essence of rightly planned arrangements, viz., a determined reference to the antiquity of the deposit. Werner is, therefore, entitled to the distinguished praise of clearly announcing and striving earnestly to establish one of the most important general laws yet ascertained respecting the structure of the earth. He proved that in a particular district its stratified rocks are laid one on another in a certain order of succession, and affirmed that the same, or a very similar order, prevailed over large parts of the earth's surface.

Mitchell.—It has been usual, especially in England, to quote a variety of persons before the date of Werner, to whom the honour of first declaring the principles developed by the professor of Freyberg might with more justice be ascribed. The nature of his obligations to his own countryman, Lehmann, has been already sufficiently stated. Mitchell, one of the ablest of the natural philosophers of England during the middle of the 18th century, who, for a short time, filled the Woodwardian chair of geology at Cambridge, and afterwards resided in Yorkshire, had certainly made himself acquainted with the series of English strata, especially in the northern counties, and had even gone so far as to discover some of the most important general relations between the geological structure and the physical features of the globe, defining with a masterly hand the mutual dependence of mountain ranges and lines of stratified rocks.

In frequent journeys between Cambridge and Yorkshire, mostly performed on horseback, he composed a useful section of the strata between the chalk hills of Bedfordshire and the coal strata of Nottinghamshire. Habitually communicating information of this kind to his friend Cavendish, Mitchell never printed an account of his discoveries; the great chemist verified, but never mentioned them; they lay concealed among the Cavendish MSS. and neglected on the back of an old letter of Smeaton, till, in 1810, the letter was seen by Farey; and, in 1844, the papers in the possession of Lord Burlington disclosed many unexpected facts in the history of his great kinsman.*

Whitehurst.—The merit of Whitehurst, also, both as a theorist and as an observer, is very considerable. He states the object of his work,† published in 1792, to be "to trace appearances of nature from causes truly existent; and to inquire after those laws by which the Creator chose to form the world; not those by which he might have formed it, had he so pleased." His mode of proceeding is exactly in conformity with the first clause of this sentence; for his whole work is a finely woven web of plausible deduction and conjecture, founded on general physical considerations, and supported or illustrated by a

* See this subject examined in Phillips's "Life of William Smith, LL.D."
† The Natural History of the Earth, by John Whitehurst.

selection of corresponding facts and observations. This inverse process is certainly, in many respects, characteristic of a cabinet geologist, and yet the volume contains abundant proof, that its author was both well acquainted with a great variety of important data in geology, and possessed of sufficient generalizations to develop their value. What is stated by Whitehurst concerning the succession of strata in Derbyshire and other parts, was chiefly derived from the miners and colliers, who, certainly, for a hundred years before the dawn of sound geology, knew perfectly the almost invariable sequence of strata in their own districts.

Saussure.—The value of Saussure's distinguished services to clear the way for legitimate inductions in geology cannot be better expressed than in the following passage of Cuvier, wherein he is compared with Werner:—

"En effet, la partie purement minérale du grand problême de la théorie de la terre a été étudiée avec un soin admirable par De Saussure, et portée depuis à un développement étonnant par Werner et par les nombreux et savans élèves qu'il a formés.

"Le premier de ces hommes célèbres, parcourant péniblement pendant vingt années les cantons les plus inaccessibles, attaquant en quelque sorte les Alpes par toutes leur faces, par tous leurs défilés, nous a dévoilé tout le désordre des terrains primitifs, et a tracé plus nettement la limite qui les distingue des terrains secondaires. Le second, profitant des nombreuses excavations faites dans le pays qui possède les plus anciennes mines, a fixé les lois de succession des couches; il a montré leur ancienneté respective, et poursuivi chacune d'elles dans toutes ses métamorphoses. C'est de lui, et de lui seulement, que datera la géologie positive, en ce qui concerne la nature minérale des couches: mais ni Werner ni De Saussure n'ont donné à la détermination des espèces organiques fossiles dans chaque genre de couche, la rigueur devenue nécessaire, depuis que les animaux connus s'elèvent à un nombre si prodigieux."*

4. **Inductive Geology principally founded on the Organic Reliquiæ.**—The grand fact upon which, in modern times, geological inquiries have hinged, the occurrence of marine animals far from the sea and deep in the solid bosom of the earth, was so far understood by the ancients, that they had ascertained the general agreement of fossil and recent marine shells, nor does there appear the least trace of doubt on this subject in their writings. But warm discussions arose concerning them among the naturalists of Italy, and at a later period, those of France, England, and Germany, countries in which marine exuviæ are particularly plentiful and various.

The 16th century was wholly wasted in the ridiculous dispute whether the fossil shells were genuine marine exuviæ, or mere *lusus*

* Ossemens Fossiles Disc. prelim.

naturæ produced by a plastic power or fermenting fatty earth? and the question assumed a more difficult character from the addition of another, whether, if they were genuine petrifactions, they were all deposited by the Noachian deluge? In examining both of these points the Italian philosophers were by far the most conspicuous, and it is difficult to understand how the sound conclusion of Fracastorio (1517), Scilla (1670),* Ramazzini,† and Vallisneri,‡ could fail to become the universal creed of geology. Palissy, the philosophic potter of France, published, in 1557,§ from his own experience, that fossil shells and other "figured stones" were the genuine exuviæ of ancient marine animals. Yet, through all Europe, the majority of naturalists, "vulgi persuasione occupati,"|| believed these admirable and venerable records to be mere *lusus naturæ*, unworthy of serious investigation, as a basis of true and sound geology. The 17th century closed before the expiration of this absurd controversy; but as truth infallibly gains strength by even the most unworthy contests, the strong interest attached to the solution of this problem spread universally among naturalists the conviction that great discoveries concerning the structure of the earth were to be accomplished, and the mode of contemplating its connection with zoology received very capital improvements.

Progress of Palæontology in England.—In England, especially, the superior interest which belonged to the thousands of fossil plants and animals, was fully understood by Plot, Llwyd, Ray, Lister, Woodward, and Moreton; who by their rich collections, and splendid publications, and resolute though unsuccessful efforts to deduce the causes which had thus buried and preserved imperishable in their everlasting tombs the organic remains of a former world, undoubtedly kindled that ardent spirit of inquiry respecting the structure of the earth, for which the English philosophers of the 17th century were honourably distinguished.

Nevertheless, the progress of geology in England was still retarded by the fettered condition of other sciences, and by a peculiarly unhappy conjunction of truth and fiction. The correct view of the original nature of "formed stones, or petrifactions," was coupled by Woodward and his numerous followers with the assertion, that all the strata superimposed on one another in the crust of the earth, with all their included myriads of fossil animals and plants, were deposited by one general flood, "the deluge!"

Italy, again, vindicates her claim to be forward in teaching phy-

* La vana speculazione disingannata, Napoli, 1670.

† De font. Mutin. Scat., b. 1633, d. 1714. His observations are quoted by Vallisneri, Lazzaro Moro, Linnæus, &c.

‡ De corp. mar., and other works, b. 1661, d. 1730.

§ Palissy's work was first printed at Lyons in 1557. The edition of 1580, usually referred to, was the third.

|| Baier. *Oryctographia Norica.*

sical truth. Ramazzini, 16th century, thus corrects the prevalent error:—Strata terræ varia, aquali ordine et distantia constanter observantur, ideoque et hæc soli accretio, tam bene distincta, multorum seculorum potius, quam communis cataclysmi tumultuarium et turbulentum opus censeri debeat.—The great Swede who quotes this passage, (Linnæus, Syst. Nat., 1770,) gives an excellent sentence of the same kind:—Cataclysmi universalis certa rudera ego nondum attigi; quousque penetravi; minus etiam veram terram adamiticam, sed ubique vidi factas ex æquore terras, et in his mera rudera sensim præterlapsi ævi.—Regn. lapid. By way of contrast take the following from Baier, (1708):—Quæ quidem opinio tam firmiter insita est animo meo, ut quotquot intueor testacea è marinis fossilia, totidem catholici illius cataclysmi monumenta videre me arbitrer, aureis velut inscripta litteris:—MEMOR. UNIVERSAL. DILUVII. Even in 1740, we find the great Italian author Lazzaro Moro*—the worthy precursor of Hutton, Playfair, Brocchi, and Lyell—gathering all his strength against the Woodwardian hypothesis of the diluvial origin of the strata, and their regularly arranged and successively deposited fossils.

This fatal error, the stumbling-block of the "theorists" of the 18th century, lay at the root of the brilliant hypotheses of Burnet, Woodward, and Whiston; and now, though discarded by every sound geologist, it remains a serious impediment to the diffusion of correct general principles. One great merit, however, strikingly characterizes the early English school of geology, even in its greatest aberrations, a thorough conviction that the organic remains entombed in the earth were the surest evidence of the revolutions which it had undergone.

Lister.—In consequence, the whole island was filled with collections of fossils, which were compared with native and exotic living species, and almost every naturalist of note from the time of Lister contributed something to the stock of information respecting them. That distinguished man, equally industrious and fortunate, and in general free from theoretical prejudice, had the glory of perceiving and of recording in a single instance the principle of mutual dependence between the strata and their organic remains, which afterwards, generalized and promulgated by Smith, became the most important instrument of investigation which has ever been presented to geology.

Speaking of a small species of belemnite, (*B. Listeri*), which is figured in his *Historia Animalium Angliæ*, he says it is found in all the cliffs as you ascend the wolds, for above a hundred miles in compass, at Speeton, Londesbro' and Caistor, but always in a red, ferruginous earth. This correct and remarkable result is a striking example of the possibility of even holding in the hands a brilliant discovery, without knowing its value, or taking any steps to ascertain its importance.

* De Crostacei et degli altri marini Corpi che si truovano su' monti. Venezia, 1740.

A century later, the perception of the same truth, in several instances near Bath, and the demonstration of its applicability to the whole secondary series of the strata of England, enabled Mr. Smith, by his own unaided efforts, to establish the geology of England on a basis from which it can never be shaken; an accurate classification of the stratified rocks, in the order of their relative antiquity, accompanied by catalogues of their organic contents, and a map of their ranges on the surface of the island in conformity with the section of the interior.

To study the monuments of nature according to the principles developed by Mr. Smith; to ascertain by the order of succession and by the organic remains what were the contemporaneous effects of the natural agents employed in the formation of the earth in all parts of the world; is the great problem of modern geology. By the aid of zoological and botanical researches we determine the relative antiquity of every species of fossil plant and animal, and assign the relative period during which its existence was continued. Orthoceratites productæ, trilobites, and many crinoidea, belong to the older and lower rocks; certain species of echini and shells mark the oolitic strata; while others belong to chalk; and a series of plants, corals, shells, and vertebral remains, lies above the chalk, but is not found below. Such inferences, drawn from observations in Europe, have been found constant even in the new world; and the powerful instrument of research thus placed in the hands of the observer, having been wielded with the caution requisite in questions of analogy, the time is arrived when the principles disclosed by Mr. Smith's researches near Bath, and illustrated by Cuvier's philosophical description of the environs of Paris, will be found universally applicable; for already the distant slopes of the Himalayah and the Andes, and the shores of Australia and Greenland, are united in the mind of the geologist who contemplates their coeval stratification.

Hypotheses.—We shall here close our short account of the growth of geology into a science, without being tempted to indulge in the vain amusement of ridiculing those crude and visionary schemes which have too long been known by the misapplied title of theories of the earth. While the paths of observation, along which alone the foundations of the science are to be sought, were hard and difficult, those of hypotheses were easy, flowery, and inviting. The globular figure of our planet, the inequality of its surface, and the occurrence of marine shells in mountains far from the sea, have been thought sufficient data for rashness and speculation to construct detailed theories of the earth, to determine the constitution of its centre, and to describe, as if they had actually beheld them, the successive revolutions which it had undergone.

These unfortunate hypotheses were most numerous and discordant

during the period when positive geology had made the least progress; with the advancement of knowledge they diminished in number and improved in consistency, and at the present moment, though every professed theory has lost its power of fettering the mind, there is a tacit but almost universal agreement in those fundamental principles of structure, and circumstances of origin, by which not only every passing theory must be judged, but to which also all good observations and sound inductions must be referred. To develop these principles in a settled order, to illustrate by their aid the geological structure of the British isles, and to connect the geology of Britain with that of Europe and the terraqueous globe at large, and thus to rise by a legitimate process to the most comprehensive inferences which the subject admits of, is the aim of the following pages.

We shall not, at the outset of our inquiry, prejudge the important questions which will arise for discussion, by deciding between Huttonian and Wernerian, or any other hypotheses; but allowing to their ingenious authors the merit of having really promoted geology by stimulating curiosity and by directing inquiry, we shall for the present neglect them altogether, except so far as they may assist us to read well and interpret aright the rich and impartial volume of nature.

CHAPTER II.

ELEMENTARY VIEWS OF THE STRUCTURE AND COMPOSITION OF THE CRUST OF THE EARTH.

Materials in the Earth.

Mean Density of the Earth.—The first question which presents itself to the inquirer into the natural history of the earth is, what are the materials employed in its construction? To answer this question fully, and in all its extent, is now, and will, probably, for ever remain impossible, because with respect to the interior of the globe we can learn nothing from direct observation, nor infer from astronomical researches anything more than that the materials, whatever they are which compose the central parts, must have there a specific gravity, very much greater than that of the rocks which appear near the surface. The mean density of the prevalent rocks hitherto discovered is about twice and a-half that of water; but the mean density of the whole terraqueous mass is at least five times that of water. We may, therefore, safely conclude that the central portions are much heavier than the external crust; but beyond this, and the information yielded by deep-seated volcanic action, all is speculation.

Specific Gravity of the Materials.—It must not be concluded that because in the central parts the materials, whatever they are, have there a specific gravity greater than those near the surface, they would also remain heavier if brought to the surface, for the compressibility of matter under pressure would necessarily tend to the condensation of the internal nucleus of the earth, and that in so high a degree, if the internal substances be of the same compressibility as those in the crust of the earth, as to make the mean density of our planet very much higher than it is known to be. Putting out of view the question of the chemical relations of the internal substances of the globe, and confining ourselves to mechanical considerations alone, we should have, as conclusions of the greatest probability which the subject admits of:—

First, that the superior density of the internal parts of the globe is occasioned by the accumulated pressure which they have to sustain.

Secondly, that the effects of this pressure in condensing the internal parts of the globe would be far more considerable than they are, were they not resisted within by some general antagonist force; such as the expansive power of heat, or an extraordinary want of compressibility among the particular substances operated on.

Thirdly, that the earth's spheroidal figure has been attained in consequence of its having formerly been entirely fluid, during rotation on its axis, and is preserved because the internal arrangement of its materials, whether solid or fluid, is in equilibrio with the velocity of its rotatory movement.

Limitation of Inquiry.—It cannot be too often or too early impressed upon the mind of the student that geology has no dependence on systems of cosmogony.

The history of its successive systems of life can be investigated without entering on the question, whether the other planets are inhabited; the revolutions which it has undergone, since it became a globe, may be subjects of successful inquiry, though we disclaim all attempt to determine from what real or fancied nebula it was condensed, or by what creative process it acquired revolution round the sun, rotation on an axis, measured proportion of water, and limited tract of surrounding atmosphere. These, and many other great and noble problems, are interesting to geology; the partial solution of them brings some useful help even to the interpretation of the earth's history; geology sympathizes with and benefits by all the knowledge of nature; but it has enough to do in its own peculiar field of research.

It is wholly a science founded on observation and inferences, and limited to the phenomena presented within a small depth from the surface of the earth. The regular disposition of the materials of our planet does indeed permit us, in many cases, to infer, with the highest

probability, what is the condition of its interior to a depth far beyond that actually visible to human eye; but still all the aids of inductive science are ineffectual to penetrate more than a few miles below the soil. It may, indeed, be the case, since the level from which volcanoes arise is uncertain, that the materials which they vomit have been derived from greater depths, but the improbability that these materials, after undergoing fusion, should be restored to their original condition, must make us hesitate to adopt volcanic products as evidence of the exact nature and condition of the substances in the interior of the earth. Our observations are, therefore, nearly confined to what is technically called the crust of the earth, and our direct inferences descend no lower than the rocks which appear in this crust.

Earthy Compounds.—There is hardly any tract of country so limited as not to show a considerable diversity of earthy aggregates. Even in those districts which possess neither quarries, nor mines, nor cliffs, nor natural valleys, the surface of the land and the shores of the sea are generally strewed with fragments of different stones transported by some ancient powerful currents from regions in which nature is more prolific, or more clearly reveals her treasures.

In the more level countries the principal varieties of the earthy compounds or aggregates are included in the terms limestone, sandstone, and clay, of different colours, hardness, and fineness of grain. Each of these great divisions of rocks contains essentially a peculiar species of earth which imparts to the mass a particular derivative character. Thus—

Lime is the base of limestone.
Silica — of sandstone.
Alumina — of clays.
Magnesia is an essential ingredient in *certain limestones*.
Carbon is the characteristic element of coal.
Soda is the basis of common salt.

If we now turn our attention to the mountainous tracts, where crystallized minerals present themselves in an endless variety of combination, we shall, perhaps, be led to expect a corresponding abundance of primitive substances. But chemistry has taught us that all this seeming inexhaustible variety is occasioned by a few earths, metals, and combustibles, and some of these are so rare, and even solitary in their occurrence, as to be of little importance in this inquiry. By far the greater number of earthy minerals are composed of the four substances, silica, alumina, lime, magnesia, variously combined with alkalies and acids, and differently coloured by metallic oxides, &c. A good general knowledge of siliceous, aluminous, calcareous, and magnesian minerals and rocks, is therefore the portion of mineralogy most essential to a geologist.

By way of marking the distinctions of geology, mineralogy, and chemistry, we may take three successive aspects of one rock, granite. The geologist considers the circumstances under which this rock is found—whether in great mass or small veins; in the axes of mountains, or in comparatively plain countries; the peculiarities of its structure on a great scale; the constituent minerals; the associated strata; the period of its fusion and eruption. He observes that it is composed of three minerals principally, so that it may be thus represented:—

Granite composed of $\begin{cases}\text{Quartz,}\\ \text{Felspar,}\\ \text{Mica, \&c.}\end{cases}$

To the mineralogist granite is an object of study, because it is composed of certain minerals, whose constant characters it is a part of his science to determine. It *is not granite* which he *studies*, but the mineral constituents of it. These he examines separately by their geometrical forms—their specific gravity, hardness, effects on light, electricity, magnetism, &c.

The quartz is gray, or purely translucent, of crystalline external form, or adapted in form to the other minerals.

The felspar is red, gray, green, white, &c., always of crystalline structure internally, often distinctly terminated by primary or secondary planes—sometimes in detached large crystals.

The mica is in brilliant plates; when perfectly crystallized, they are six-sided; the colours black, gray, white, &c.

Finally, the chemist takes these separate minerals and *analyzes* them, resolves them into their several ingredients or chemical elements—examines the properties and proportions of these, and investigates the laws of their combination. The result of the whole process may be thus represented:—

Granite.	Quartz.		Silicium	48·4
			Oxygen	51·6
	Felspar.	Silica	Silicium	48·4
			Oxygen	51·6
		Potash	Potassium	81·5
			Oxygen	18·5
		Alumina	Aluminium	53·2
			Oxygen	46·8
	Mica.	Silica	Silicium	48·4
			Oxygen	51·6
		Potash	Potassium	81·5
			Oxygen	18·5
		Magnesia	Magnesium	61·4
			Oxygen	38·6
		Per-Oxide of Iron	Iron	70·0
			Oxygen	30·0
		Lime	Calcium	71·3
			Oxygen	28·7

By such researches carefully conducted it appears that one-half of the ponderable matter near the earth's surface is composed of an element which, released from combination, expands 2000 times at ordinary temperatures, and becomes oxygen gas, a constituent of our atmosphere.

Elementary Substances.—All the various aerial, liquid, and solid compounds which belong to this globe are reducible to about sixty-three ingredients, which are termed simple or primitive, because, in the present state of chemical science, they appear incapable of further decomposition. Of these

Fifty-one are *metallic bodies*, brilliant, electropositive, and, with the exception of potassium and sodium, heavier than water.

Ranged in the order of their affinity for oxygen we have the metals in the following three groups:—

First Group.—Six absorb oxygen at all temperatures, and decompose water at all temperatures. Of these three are bases of the alkalies, those marked * being most abundant.

Potassium,* sodium,* lithium.

Three are bases of alkaline earths, that marked * being most abundant.

Barium, strontium, calcium.*

Second Group.—Thirty-six? absorb oxygen at high temperatures. Never decompose water at temperatures below 122° F.

Of these the following seven are bases of earths, those marked * being most abundant.

Magnesium,* aluminium,* thorium, glucinium, zirconium, yttrium (silicium*. This not always ranked as a metal).

Another group consists of—

Manganese, zinc, iron, tin, cadmium, cobalt, nickel.

Another of—

Arsenic, chromium, vanadium, molybdenum, tungsten, columbium, antimony, uranium, cerium, bismuth, titanium, tellurium, copper, lead.

Of the following eight metals as yet little is determined:—Erbium, terbium, didymium, lanthanium, niobium, norium, ilmenium, pelopium.

Third Group.—Nine part with oxygen at high temperatures:—

Mercury, silver, gold, platinum, palladium, rhodium, osmium, iridium, ruthenium.

Eight non-metallic combustibles,—

Sulphur,	Iodine,	Carbon,
Phosphorus,	Bromine,	Fluorine?
Selenium,	Boron.	

Four gases,—

Hydrogen,	Oxygen,	Azote,	Chlorine.

Every substance in this list is found in the mineral kingdom; and while the chemist examines them separately in his closet, the mineralogist studies their combinations in the field.

Minerals.—It may, perhaps, be imagined that innumerable combinations are derived from these sixty-three primary ingredients. But as many of them are excessively rare, as the remainder combine only

upon certain principles, the number of mineral species really determined is, in fact, not large, perhaps hardly exceeding 500. Nor is the geologist always called upon to make himself acquainted with all even of this moderate number. Unless his labours are devoted to the detailed phenomena of volcanic productions, or of mineral veins, he will seldom have occasion to observe more than one-tenth of the number. The reason of this is that a large portion consists of rare and local species, and that, in combining to form rocks, the others are associated in families, and united into specific compounds without much permutation. Thus, quartz, felspar, hornblende, chlorite, and mica, frequently occur together in granitic rocks, but other minerals, as calcareous spar, &c., scarcely ever accompany them. In consequence, then, of the rarity of many minerals, and the uniformity of the assemblage of others, there is really much less difficulty than might be expected in recognizing and discriminating the rocks. To class and to describe them in a true natural order is difficult, to compare and to know them according to their mode of occurrence is easy.

Supposing, then, that the student has already made himself acquainted, by examination of a few specimens properly labelled, with the more common and remarkable rocks, as limestone, sandstone, and clay, various kinds of slates, basaltic, porphyritic, and granite rocks, we shall now proceed to inquire in what manner they are arranged in the earth.

Stratification.

The best way of prosecuting this inquiry, is to begin at home, where precise information can be most easily acquired; next to compare our own with neighbouring districts; and, finally, extending our views over the whole surface of the globe, to class the phenomena, and deduce the general results.

Arrangement of Rocks on the Surface.—It might be very excusable before countries were cleared and cultivated, and before their various mineral productions were employed and understood, to imagine that the materials of the earth were heaped together in confusion, the result of a chaotic formation; but at present, such a notion will not stand the test of a moment's reflection. One district has chalk beneath the surface, another limestone, a third coal, and a fourth granite, and these are never mixed or confounded together; so that the most careless observer must conclude that the different rocks are arranged after some ascertainable method. These different rocks are not mere insulated patches irregularly scattered through the country, but generally connected on the surface in long ranges, which in all the eastern half of England have their prevailing direction from north-east to south-west. Thus the chalk of the Yorkshire wolds is

prolonged (see the Map of the British Isles) through Lincolnshire, Norfolk, Suffolk, Bedfordshire, Wiltshire, Dorsetshire, &c.; the oolitic limestones range through Lincolnshire, Northamptonshire, Gloucestershire, and Somersetshire; and many other limestones and sandstones hold a parallel direction. Hence it happens, in proceeding from London toward the south-west, west, or north-west of England, that we cross so great a variety of rocks, and so many ranges of hills.

A person proceeds from London to North Wales. After passing low, gravelly plains in the drainage of the Thames, he climbs, by a long slope, the chalk-hills of Oxfordshire; crosses vales of clay and sandstone; ascends a range of oolitic limestone; traverses wide plains of blue and red marl; arrives in districts where coal, iron, and limestone abound; and, finally, sees Snowdon composed in great measure of slate. And if, in proceeding from London to the Cumberland Lakes, he finds the same succession of gravelly plains, chalk hills, clay vales, oolitic limestone ranges, blue and red clays, coal, iron, and limestone tracts, succeeded by the slate rocks, which compose the well-known summit of Skiddaw, will he not conclude that something beyond mere chance has brought together these rocks in such admirable harmony? Will he not have reason to conjecture that in the *interior* of the earth regularity of structure must prevail?

Internal Arrangement of Rocks.—This conjecture becomes certainty when we explore the relative position of rocks as it is displayed in wells, pits, quarries, and mines, the works of human industry, or laid bare in cliffs and ravines by the hand of nature. Here we see the rocks formed in layers or tabular masses of various thickness, but always of very great superficial breadth or extent, and placed upon one another like the leaves of a book. These layers are called strata. Along the edges of hills, in the course of precipitous valleys, and by the margin of the sea, it not only is not difficult to recognize this truth, but it is almost impossible to avoid perceiving it.

Many parts of the English coast present what is termed a natural section of the rocks, and accordingly, whoever visits the shores of Northumberland, Yorkshire, Kent, Hampshire, Cornwall, South Wales, or Cumberland, may easily satisfy himself of the stratification of most of the limestones, sandstones, clays, and slates of England. For most of the cliffs are composed of several distinct layers of rock, which are piled one upon another in a regular order, preserve a definite thickness, and appear under the same circumstances in many distant places. In the interior of the country the same conclusion is to be drawn from examining precipitous hills and deep valleys; and even in the flattest country, art supplies the means of investigation which nature has denied. The wells, and pits, and mines, which have been found necessary for the comfort of civilized man, all dis-

play the same general truth, and lead us to conclude that the principle of stratification among rocks is confined to no particular country, but whether in the New or the Old World, in continents or in islands, it is so remarkable and so constant, that colliers sink deep pits, and miners undertake extensive levels, in full confidence that no exception to its generality will affect the result of their enterprises. It is not a speculative truth, but a practical law of nature, and is probably the fact of most extensive influence in the whole theory of geology.

So many important facts respecting stratified rocks flow in together upon the observing mind, that it is not easy to analyze them in the exact order of their occurrence. A person attentive to the subject cannot fail to discover, even in a very limited district, that the different strata which appear above one another, like the leaves of a book, are also, like them, arranged in a certain constant order of succession. A stratum which in any one situation is found beneath another will never, in any other situation, be found above it.

Superposition of Strata.—As a bookbinder sometimes neglects to bind in a particular leaf, so nature sometimes omits a particular rock; but she never misplaces the rocks, as the careless workman sometimes misplaces his pages. Let us take, as an example, the cliffs on the coast of Yorkshire, between Flamborough Head and Robin Hood's Bay. Gristhorp Cliffs are crowned by calcareous sandstone rocks, which rest on a thick, bluish, argillaceous bed; under this is a brown, ferruginous sandstone, and, still lower, a thin, calcareous layer full of fossil shells. In Scarborough Castle Hill, the same calcareous sandstone, argillaceous bed, brown ferruginous rock, and fossil bed, occur in the very same order of succession. Or let us station ourselves at Leeds, and examine the coal-pits of the neighbourhood, notice how many seams of coal are cut through, and what beds of sandstone and shale, and what layers of ironstone are met with. Then, inquiring of the workmen, we shall learn that the same "set of beds" is wrought at another pit. At this other pit we shall find the same beds of coal in the same order of succession, at nearly the same distances from one another, and of nearly the same qualities and thicknesses; and this strict analogy will be found at several pits over a considerable extent of ground, and, therefore, here, as well as on the coast, we obtain proof that in a limited district the *strata are arranged with respect to one another in a certain constant order of succession.*

Inclination of Strata.—Pursuing our investigation, we find that the strata are generally so disposed that their planes or broad surfaces are not exactly level or parallel to the earth's spherical surface, but sloping in some one direction, so as, in that direction, to sink deeper and still deeper into the earth, and to be covered by other

strata. This slope, this deviation from the horizontal position, is called the dip or inclination of the strata; and the rocks are accordingly said to *dip* or *incline* to this or that part of the horizon. The different rocks which compose the interior to a considerable depth are, therefore, in consequence of this inclination, exhibited in succession on the surface, and hence it is that mankind is furnished with a vast variety of mineral productions suitable to its numerous necessities.

Continuity of Strata.—Any one thus far initiated in geology, and possessed of common powers of observation, will be able to compose a list or scale of the strata which occur in his own neighbourhood, naming them in the exact order of their succession or superposition, and thus will be furnished with the means of comparing his own district with others near and distant. The results of this comparison are very important, for we thus learn that one general order of succession is observed among all the stratified rocks of England. Certain strata are locally deficient, but all those which do occur together are found invariably in the same relative position. The series of stratified rocks in the north of England, taken in a general way, is expressed by the following names:—chalk, gault, Kimmeridge clay, coralline oolite and calcareous grit, Oxford clay and Hackness rock, cornbrash and Bath oolite rocks, lias shales, red marl and sandstone, magnesian limestone, coal system, mountain limestone, slate. The series in the southern parts of England is precisely accordant, except that the magnesian limestone is there nearly deficient, and that the Kimmeridge clay is covered by some strata which do not pass the river Humber. Besides, we find the strata of the north of England actually connected by mutual extension with those of the same names in the south of England, so that we thus prove their continuity over large tracts, as well as the constancy of the order of their succession.

By means of these comparative observations, begun by Mr. Smith in 1790, and continued with unabated zeal by his numerous disciples, the whole series of English stratified rocks has been ascertained, and arranged in tabular order; and the geologists of England have, in consequence, furnished to the rest of the world a standard of comparison, by which to determine how far the laws of stratification disclosed in this island are applicable to other countries.

The following table, taken almost verbatim from Dr. Fitton's valuable notes on the History of English Geology, (*Phil. Mag.* 1832,) presents the list of English strata as published by Mr. Smith in 1815, and the corresponding arrangement admitted among geologists; and thus at one view may be seen the entire distinctness of Mr. Smith's whole system of classification and method of naming, from that of any earlier continental writer, and the almost perfect exact-

ness with which his views and names have been adopted by the modern school of English and European geology.

Characters of Natural Districts formed by Groups of Strata.	No.	Names of Strata on Mr. Smith's Map and Sections, 1815.		Names used by English geologists, 1832.
		(*These beds above the chalk not noticed by Smith*)		Crag of Suffolk. Marine and Freshwater strata of the Isle of Wight and Dorsetshire.
Plains	1	London clay	Strata above the chalk	London clay.
	2	Clay or brick earth		Plastic clay.
	3	Crag (*this should have been placed first*)		Sands above the chalk.
	4	Sand and light loam		
Chalk hills	5	Chalk { Upper with flints / Lower, without flints }		Chalk { Upper, / Lower.
	6	Green sand	Cretaceous strata	Upper green sand.
Clay vales	7	Blue marl		Gault.
	8	Iron sand		Lower green sand.
		The Wealden group not distinguished by Smith.	Wealden	Weald clay. Hastings sands. Purbeck limestone.
	9	Portland Rock	Upper oolite.	Portland oolite.
	10	Sand		Sand.
	11	Oaktree, or North Wilts clay		Kimmerige clay.
	12	Coral rag and pisolite	Middle oolite.	Upper calcareous grit. Coralline, or Oxford oolite
	13	Sand and Sandstone, or calcareous grit		Lower calcareous grit.
	14	Dark blue, or Clunch clay		Oxford clay.
	15	Kelloway stone		Kelloway stone.
Stonebrash hills	16	Cornbrash	Oolite strata. Lower oolite.	Cornbrash.
	17	Hinton sand and sandstone		Sand and sandstone.
	18	Forest marble		Forest marble.
	19	Clay		Bradford clay.
	20	Great oolite		Great oolite.
	21	Fullers' earth and rock		Fullers' earth and rock.
	22	Under oolite		Inferior oolite.
	23	Sand		Sand and grit.
	24	Marlstone	Lias	Upper lias clay. Marlstone.
Marl vales	25	Blue Marl		Lower lias clay.
	26	Blue lias		Blue lias.
	27	White lias		White lias.
	28	Red marl and gypsum	Saliferous strata	Red marl and gypsum. Red sandstone.
	29	Magnesian limestone		Magnesian limestone. (Zechstein, &c.)
Coal tract		Soft sandstone		Rothetodteliegende.
	30	Coal districts	Carboniferous strata	Coal measures.
Mountainous	31	Mountain limestone		Mountain or carboniferous limestone.
	32	Red and dun stone		Old red sandstone.
	33	Various, killas or slate. The analysis of this great series was begun in 1831, by Murchison and Sedgwick.		
	34	Granite, syenite, and gneiss		Granite, &c.

Stratification a General Principle.—Considerable labours remain to be accomplished before even the stratified rocks of Europe can be

completely compared with those of England, and the want of evidence is still more severely felt with respect to the three other quarters of the globe. Nevertheless, the following important general results may be regarded as certain. The *principle of stratification* is found to be *universal;* that is to say, in every country of sufficient extent, various rocks are found to be superimposed on one another in a certain settled order of succession, and these rocks are not found only in insulated patches, but often hold their course across provinces and kingdoms.

Throughout the whole area of Europe, from the Oural mountains to the Atlantic, and from Lapland to the Mediterranean, the stratified masses of the earth, taken in their generalities, are arranged upon the same principles, follow one another in the same exact order of succession, and, in fact, form parts of one vast system of rocks, once more perfectly connected than at present.

What is known of the geology of North Africa, Egypt, Syria, the countries bordering on the Caspian, Siberia, and Hindùstan, leads to a confident belief that the same general system, modified by local circumstances, will be found applicable to the greater portion of the surface of the Old Continent.

Analogy of Distant Deposits.—Important agreements between the strata of North America and New Holland and those of Europe, have been already determined, and the time will probably at last arrive, when, though it cannot be proved, as Werner perhaps imagined, that similar rocks were at the same time deposited in every part of the bed of the ancient sea, at least it will be possible to show that the same system of natural processes was everywhere in progress, contemporaneously or successively producing analogous effects; and to ascertain the relative antiquity and accompanying circumstances of even the most distant deposits; and thus to exhibit, in chronological order, a history of all the varied yet harmonious operations, by which, in regular gradation, this globe was filled with long-enduring monuments of the everlasting power and wisdom of its Creator, and made fit to be inhabited by a being capable of interpreting the conditional effects, recognizing the appointed agency, and venerating the universal cause.

Distinction of Stratified and Unstratified Rocks.

Relative Situation.—Stratification is, therefore, the most general condition, or mode of arrangement of the rocks which appear in the crust of the earth; and in the wide plains and gently undulated portions of the surface, it is often the only one discoverable. A person of good discernment, who should pass his whole life in investigating the south-eastern part of England, or the northern part of

France, might conclude, from every observation he could there make, that the external materials of the earth were *universally* stratified.

On the other hand, the inhabitant of the mountains sees so many examples of granitic rocks, totally devoid of any appearance of stratification, and sometimes finds that structure in the slate rocks so dubious and inconclusive, that he is wholly unable to comprehend the magnificent chain of inductions derived from the study of stratified rocks. Unstratified rocks generally abound along mountain chains and groups, and very often form their axis or nucleus. Stratified rocks fill the plains, and form the encircling flanks of the mountains. When a vast mass of unstratified rock, as granite, forms the nucleus of a mountain group, the stratified materials which surround it generally slope away on all sides, as if the granite had been protruded from below these strata, and, during the act of its uplifting, had broken them, and caused them to assume their several inclinations. Other unstratified rocks, as basalt and porphyry, appear amongst the stratified rocks, sometimes in irregularly lenticular masses, as if they had been spread in a melted state around a common centre, sometimes filling long vertical fissures in the strata, as if they had been injected from below.

Mineral Characters.—On comparing together the stratified and unstratified rocks, we find their mineralogical composition extremely different. The *stratified rocks* are earthy aggregates, as sandstones, clays, or simple chemical precipitates, as limestone; such materials, in fact, as we know to be accumulated in the same mode of arrangement by modern waters.

The *unstratified rocks*, on the other hand, are generally and evidently crystallized masses, often analogous to volcanic products, or compounds containing essentially minerals which are not known to be producible from water, but in several instances are obtainable by artificial heat, or generated in the deep furnaces of which volcanic mountains are the vents.

Stratified rocks have evidently been deposited successively from above; the lowest first, the uppermost last, in obedience to the laws of gravity.

Unstratified rocks, on the other hand, seem to be derived from the depths of the earth, and to have been ejected or uplifted from below the strata, as volcanic matter is protruded at the present day.

Contents.—Stratified rocks contain very generally the remains of the plants and animals which were in existence at the period of their formation, exactly as remains of the present races of plants and animals are found buried in the modern deposits of water.

But unstratified rocks contain no such evidences of watery origin or mechanical aggregation.

Origin.—By all these characters, separately and comparatively

considered, the two great divisions of materials which compose the external parts of our globe are proved to have been produced by entirely opposite causes. Stratified rocks are analogous to the modern products of water, and are therefore called Neptunian, while unstratified rocks are analogous to the modern products of subterraneous fire, and receive the names of Plutonic and Volcanic, according to the degree and circumstances of this analogy.

There are some cases of the production of strata enveloping shells and plants, &c., by the action of wind—Eolian strata, as Nelson calls them in his account of Bermuda.*

Mode of Study.—The distinction now insisted upon between the Neptunian and Plutonic formations, between rocks of deposition and rocks of eruption, is of the highest importance, and deserves the first notice, even on the very opening of the subject of geology. For not only are these different classes of rocks distinguished by most important general characters, but even the methods by which they are to be investigated, and the preliminary knowledge required for this purpose, are entirely distinct. Amongst the stratified rocks a knowledge of zoology and botany is required to develop the past history of innumerable remains of plants and animals, which were buried at successive periods; on the contrary, among the mountains associated with granite, where minerals of every hue and form appear in every different combination, scientific mineralogy is of much higher importance.

In consequence, geology divides itself into two branches, one of which links itself with the natural history of modern plants and animals, and the other with chemistry and mathematics. And we have now, and have always had, two distinct groups of geologists, whose progress and discoveries have been as different as the preliminary knowledge which their different spheres of research required.

A geologist of adequate attainments must indeed be supposed acquainted, at least generally, with both branches of this magnificent subject; and therefore a person entirely ignorant either of mineralogy, on the one hand, or of zoology and botany on the other, must be considered as only half-educated. He may, indeed, be a very useful local observer, but he must be further instructed in his science before he can be sent to explore an unknown region, or permitted to give an opinion on the whole theory of geology.

As much knowledge, therefore, as can be easily gained of the minerals which enter most frequently into the composition of rocks and veins, and of the natural history of the plants and animals whose remains lie buried in the strata, is absolutely necessary to every professed geologist. Yet on this account the student ought by no means to be discouraged; for this preliminary knowledge will be quickly,

* Nelson in Proc. of Geol. Society.

though insensibly, acquired by an intelligent observer, in exact proportion to his need of it. In a level country composed of limestone, sandstone, and clay, the multitudes of organic remains which continually meet his eye will infallibly procure him the power of discriminating their specific forms; and among the mountains associated with crystalline granite, the endless repetition of the objects will generate a mineralogical tact in the eye, and a mechanical, if not mathematical, notion of the structure of crystals.

The summary observations which will be introduced in this treatise on the preliminary sciences of zoology, botany, and mineralogy, will be placed with those divisions of the subject to which they respectively belong, and where they will be the most intelligible as well as the most useful.

On Stratification in general.

Strata, the term Defined.—*Strata, layers, and beds are synonymous terms.* "Strata," says Professor Playfair, "can only be formed by seams which are parallel throughout the entire mass." This definition, founded upon the supposition that loose materials deposited under water must be arranged in layers parallel to the surface of the water, undoubtedly contains the general or fundamental idea of stratification, but is often too abstract for practice. It includes too much, for slaty cleavage produces laminæ more truly parallel than Neptunian strata; and it excludes many layers produced under greatly agitated water, on lines of sea-coast, and in the direction of sea-currents. The most remarkably regular and parallel seams or divisions between strata happen in calcareous and argillaceous rocks; but the partings in sandstone are much less uniform. A particular shelly bed of stone lies at the top of the coralline oolite of Yorkshire, and may be traced for a great distance; a red band, long since noticed by Lister, lies at the base of the chalk of Yorkshire and Lincolnshire for sixty miles in compass; the cornbrash limestone, seldom more than ten feet in thickness, is continuous from Dorsetshire nearly to the Humber. In these instances, therefore, Playfair's definition applies very well. On the contrary, the beds of sandstone with coal which are interposed in the oolite system of Yorkshire, are altogether 500 feet thick near Robin Hood's Bay, but dwindle toward the south, and are entirely deficient before reaching the Derwent.

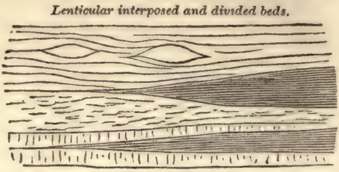
Such beds are therefore wedge-shaped; and cases sometimes occur where, by attenuation in all directions from the centre, they become lenticular. See fig. 4 for these and other appearances.

Interposed Strata.—The strata, therefore are not all co-extensive. Limestones and thick clays are probably the most persistent and

regular, sandstones the most limited and local. *Local* or *interposed beds* cause the principal differences between distant portions of the same formation.

The lias of England rest immediately upon red and bluish marly clays with white gypsum; at Luxemburg they are separated by a thick sandstone. In the north of England, magnesian limestone separates the coal from the upper red sandstone; but in other parts of the island these two formations are in contact. In the breast of Ingleborough, the limestone beds are aggregated into one vast mural precipice or scar; but as we proceed northwards this mass opens to admit layers of sandstone, shale, and coal, which gradually increase under Crossfell, and swell out to a vast thickness in Northumberland, so as to contain several valuable seams of coal, thick rocks of sandstone, and abundance of shale, between the horizontally separated beds of limestone.

Lenticular interposed and divided beds.



4

The oolitic strata near Bath are composed of two portions—the upper or great oolite, and the lower oolite—and between them is a series of calcareous and argillaceous beds called fullers' earth beds, sometimes 150 feet thick. As we proceed northward into Lincolnshire, the fullers' earth beds are excluded from the series; still farther north the whole series is changed; so that in Yorkshire it includes thick layers of sandstone, shale, and coal. On a first view the districts of Bath and Yorkshire are very unlike, but the contemporanity of their deposition is certain from the continuation of the same oolitic beds through both of them.

Thickness.—The *thickness* of the beds or strata varies exceedingly, and seems to have reference to the rapidity, regularity, and continuity of the deposition, and the rate of drying or consolidation of the materials.

The chalk rock is about 500 feet thick, and in all this great mass we can scarcely trace any decided beds; though the layers of flint at equal distances (four to eight feet,) and the difference of the organic remains at different depths, evidently prove a succession of stratified deposits.

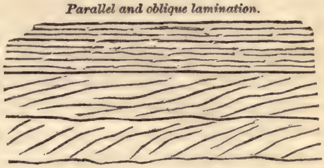
The great oolite near Bath is, on the contrary, divided into *a certain number* of beds, definite in quality, thickness, and order of position.

Laminæ.—A certain stratified rock, therefore, is composed of one or more layers of strata, but this is by no means the last term of the analysis. Each bed is often composed of many laminæ, which are sometimes parallel to the plane of the bed itself, and sometimes lie

in it at different angles. Thus micaceous laminated sandstones, and in particular the best flagstones of the coal districts, are composed of a multitude of thin layers parallel to the plane of the bed, and entirely covered by plates of mica, which probably cause the splitting of the stone. This appearance is very analogous to the laminated sand quietly left by the successive floods of a river.

But the coarser flagstones of the same coal districts are often composed of laminæ, laid at various angles to the plane of the bed, and in consequence producing a rough, uneven, shattery surface, and a tendency to oblique fractures; thus, in fig. 5, *a* represents the regular, and *b* the coarse, irregular flagstones.

Parallel and oblique lamination.



5

Such appearances of oblique lamination are occasionally found in the modern sediment of agitated waters, both in the banks of rivers and on the sea-shore.

When these oblique laminæ extend through thick beds, they sometimes cause a slight difficulty in determining the dip of the strata, and are then called *false bedding*. Some of the coarse upper beds of the great oolite of Bath, Gloucestershire, Northamptonshire, and Lincolnshire, as well as of Normandy, are remarkable for this false bedding.

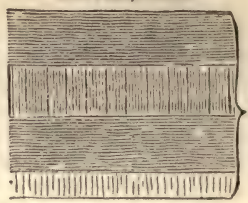
But it is in the coarse sandstones that we see the most remarkable examples of this structure, as on the coast at Scarborough, and under Nottingham castle.

The more violent the action of the water, the less regular is the internal constitution of the layers found beneath it. Let any one with this view compare the effects of the tide beating upon the sand and pebbles of the eastern coast, or the tumultuous products of a mountain river, with the tranquil deposit and sediment on the alluvial lands near Lynn and near Hull. In the former case the materials are frequently found heaped together in laminæ, variously and confusedly inclined to one another; in the latter they are all parallel to the horizon, and to the general plane of the surface. The former case is exactly analogous to the false bedding mentioned in a preceding section, so general in our sandstone conglomerates, and in shelly beds of oolite; the latter is exactly like the regular lamination of clays and shales. Like effects flow from like causes, and thus we are enabled to frame very plausible conjectures concerning the condition of the waters under which the several strata were accumulated.

General Terms.—In the same way as a number of similar laminæ are sometimes united into one bed of stone, so several similar beds of

stone are sometimes associated into one rock, to which a specific name is applied, as the oolite, the lias limestone, &c.

Sometimes several of these rocks are grouped under the title *formation*, as the Bath oolite formation. Thus the lias limestone beds, the lower lias clay, marlstone beds, and upper lias clay, as represented in fig. 6, are all included in the lias formation, which rests upon the red sandstone formation, and is covered by the Bath oolite formation.



6

Series of British Strata.—The following table exhibits a complete view of the whole series of British strata, grouped, according to their relative antiquity, into three leading divisions, the primary, or Hypozoic and Palæozoic; secondary, or Mesozoic; and tertiary, or Cainozoic strata; it being understood that such divisions are chiefly adopted for convenience, as expressing with considerable accuracy certain general analogies of origin, composition, and organic contents, which prevail amongst the members of each division, but yet are not to be considered as exclusively belonging to them.

Two of these divisions are again subdivided, upon exactly the same principles, into systems of strata, which are marked by certain recurrent rocks, striking analogies of composition, organic reliquiæ of similar types, and positions derived from convulsions of the same epoch.

The systems are again usefully divided into formations; these into their several component rocks; whose ultimate analysis gives the strata, beds, and laminæ of composition. The superficial accumulations of gravel, sand, peat, &c., which are classed under the head of diluvial and alluvial deposits, are not included in this list of strata.

For the sake of the student to whom the mode of considering the sequence of rocks may not be familiar, the strata are here placed in the same order as they would be found on proceeding from the surface downward; but the numbers are placed in contrary order, to indicate succession of time, upward. This table should be compared with that of Smith, p. 23, and of Werner, p. 8.

Tertiary or Cainozoic Series of Strata.

Partly lacustrine, but principally marine, sandy, and argillaceous, and with some calcareous deposits, abounding in shells and other organic exuviæ, closely analogous to existing species.

Formations.		Subdivisions.
Postglacial	Mostly fresh water and estuary deposits	Historical. Prehistorical.
Glacial	Mostly marine, deposits of clay, boulders, gravel, &c.	
Preglacial	Fresh water estuary and littoral deposits.	
Crag	Littoral, shelly, and coralline group	Red crag, shelly. Coralline crag.
Fluvio Marine	Limestones, marls, sands, &c., on the Isle of Wight	Hempstead series. Bembridge series. St. Helen's series. Headen series.
London clay	Marine groups of clay, sand, &c.	Upper or Barton clay group. Middle or Bracklesham sands. Lower or Bognor group.
Plastic clay	Group of clays, sands, lignites	Woolwich beds. Thanet sands.

Secondary or Mesozoic Series of Strata.

Principally of marine origin, with rare and local estuary deposits; consisting of repeated alternations of limestone, flint, sandstone, sand, clay, iron ore, coals, salt, &c., with organic remains, generally very distinct from existing forms of animals and plants.

Formations.	*Upper Mesozoic Strata.*	Subdivisions.
Chalk	Calcareous with flints	Upper chalk softer. Middle chalk harder. Lower chalk marly.
Green sand	Sands more or less coloured by silicate of iron, and clays	Upper green sands. Gault clay. Lower green sand.
	Lower Mesozoic Strata.	
Wealden	A fluviatile and estuary deposit of sands, clays, &c.	Weald clay. Hastings sands. Purbeck limestones.
Upper oolite	Calcareous, with sands and clays	Portland oolite. Kimmeridge clay.
Middle oolite	Calcareous, with sands and clays	Upper calcareous grit. Coralline oolite. Lower calcareous grit. Oxford clay Hackness rock. Clay.
Lower oolite	Calcareous, with clays and sands *	Cornbrash. Hinton sands. Forest marble. Bradford clay. Great oolite. Fullers' earth rock. Inferior oolite. Feruginous sand.
Lias	Limestone and clay or shale	Upper lias shale. Ironstone and marlstone. Middle lias shale. Lias limestone. Lower shales and bone be

* This series is taken from the south of England. A different type appears in the north.

Lower Mesozoic Strata.

Formations.		Subdivisions.
Poikilitic series.........	Variously coloured clays, sands, &c......................	Upper variegated marls, gypsum, salt. Keuper sandstone. Lower variegated marls. Red and white sandstone. Red and white conglomerate.

Primary or Palæozoic and Hypozoic Strata.

The Palæozoic rocks, containing organic remains, mostly of marine tribes, and generally extinct; the Hypozoic rocks deficient of fossils.

Upper Palæozoic Strata.

Permian series	Limestones, clays, sandstones.	Knottingley limestone. Gypseous marls. Bolsover limestone. Marl slate. Rotheliegende.
Coal series	Sandstones, clays, ironstones, coal.	The subdivisions are of a local character, millstone grit lying at the base in many districts.
Mountain limestone ...	....	The subdivisions are of a local character.

Middle Palæozoic Strata.

Old red or Devonian series..................	Limestone, sandstone, clay, shale or slate................ .	The subdivisions are of a local character, constituting two distinct types.

Lower Palæozoic Strata.

Ludlow	Arenaceous and argillaceous...	Tilestone. Upper Ludlow Aymestry limestone. Lower Ludlow.
Wenlock.................	Calcareous	Wenlock limestone. Wenlock shale. Woolhope limestone. Mayhill sandstone.
Caradoc..................	Sandstones, &c.	
Llandilo.................	Calcareous, &c...................	
Festiniog	Slates, &c.........................	Arenig slate and porphyry. Tremadoc slate. Lingula flags.
Bangor..................	Grits and Slates.	Harlech grits. Llanberris slates. Longmynd slates.

Hypozoic Strata.

Mica schist, including chloritic schist, talc schist, quartz rock, granular limestone, &c.
Gneiss, including limestone, hornblende, schist, &c.

Granitic rocks, which are not stratified, usually form the basis of the strata, and are frequently, but not by any means universally, followed by the gneiss and mica slate system.

Disturbed Stratification.

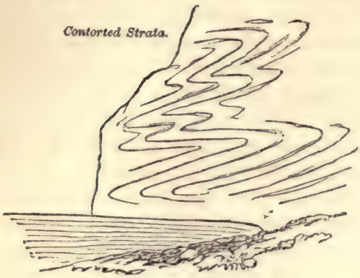
Strata originally Level.—All strata, says Cuvier, in his admirable *Discourse on the Revolutions of the Globe*, must necessarily have been formed horizontal; and this opinion, founded upon the admission that rocks composed of regular layers, containing rounded pebbles and organic remains of water-animals, can only have been formed under water, is supported by observation. For not only do we see at the present day the deposits of water arranged in planes nearly or exactly horizontal, but we also find the ancient strata of the earth, where undisturbed by convulsions, very nearly level. In consequence of these disturbances the strata are seldom found to be perfectly horizontal, but are often inclined at high angles, and in a few instances stand directly vertical. Their planes are generally continuous over large spaces, but they are sometimes broken and dislocated by *faults* or *dykes*. It is now generally admitted that the usual horizontal disposition of the strata is derived from the action of the supernatant waters which accumulated them; and that the irregular declinations and fractures which we sometimes behold are the effects of subterranean convulsions, chiefly occasioned by internal expansion. The truth of these opinions will appear from a few plain considerations.

Subsequently Disturbed.—Earthy matter deposited from water by tranquil subsidence, as clay and limestone, or accumulated during periods of moderate agitation, as sand and sandstone, must in general be accumulated into layers or strata, proportioned to the intervals of deposition; and these layers, in consequence of the fluctuation of the water and the influence of gravitation, will especially tend to be horizontal. Nevertheless they must, in a considerable degree, accommodate themselves to the surface on which they are deposited. If the bottom be level, so will be the deposit; if sloping, the deposit will be inclined; but if there be a perpendicular subaqueous cliff, no deposit can fall upon its face, nor any transported materials be accumulated parallel to it. An originally perpendicular layer or deposit of earthy materials is obviously impossible. Whenever, therefore, we behold vertical strata, we may be quite sure that they were not deposited in that form, but have been displaced by some internal movements of the earth.

Vertical Strata.—Abundance of instances of this remarkable position of strata may be quoted in almost any part of the world. The Isle of Wight gives us a magnificent series of strata, 1100 feet in thickness, reared into an absolutely vertical position; and this effect is the more remarkable, because the materials uplifted consist of many strata of loose sands and pebbles, which most certainly have been deposited nearly level. In the western borders of Yorkshire, vertical strata of limestone range for miles parallel to the edge of the Pennine

chain, and turn eastward through Craven, below Ingleborough and Pennyghent, to Settle. Magnificent examples of vertical strata are familiar to those who have visited the cliffs of Savoy, or who have perused the graphic descriptions of Saussure.

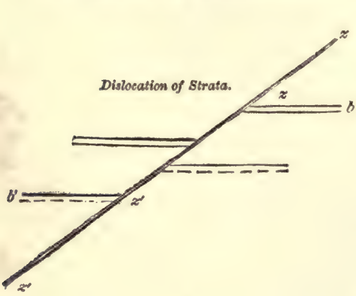
Contorted Strata.—There are some remarkable instances of contorted stratification very difficult to be explained without supposing the strata to have been soft at the time of the flexure. Not to dwell on inferior examples, we shall quote the magnificent phenomena of this kind which are seen in the valleys of Chamouni and Lauterbrun, and along the shores of the Lake of Lucerne, near Fluellen. The stratified limestones of these localities are bent with such extraordinary retroflexions, as to imply repeated or continual operations of the most violent mechanical agency, producing displacements in different directions; and observations along the range of the Alps prove that the whole of this chain has been the theatre of enormous and reiterated convulsions.



7

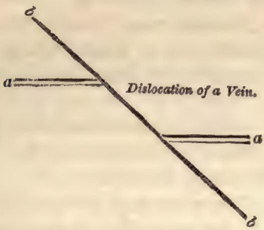
Faults.—But the most remarkable case of disturbance is when strata, either horizontal or inclined, are broken, so that on one side of the line of fracture the rocks are much higher than on the other. This difference of level sometimes amounts to 100 or even 200 yards. The succession of strata is on each side the same, their thickness and qualities are the same, and it seems impossible to doubt that they were once connected in continuous planes, and have been forcibly and violently broken asunder.

The plane of separation between the elevated and depressed portions of the strata is sometimes vertical, but generally sloping a little. In this case a peculiar general relation is observed between the inclination of this plane and the effect of the dislocation. In fig. 8, for instance, the plane of separation, *z z*, slopes under the depressed, and over the elevated portions of the disrupted strata, making the alternate outer angles *z z b*, *z′ z′ b′ acute*. In

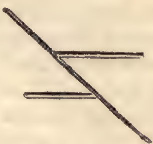


8

several hundred examples of such dislocations which have come under the notice of the writer of this essay, he rarely found an exception to this rule. A similar law is found to prevail very generally in the crossing of nearly vertical mineral veins; for instance, in fig. 9, *a a* are two portions of a metallic vein, dislocated by another vein, *b b*. In this case the relation of the line *b b* to the lines *a a*, is



9

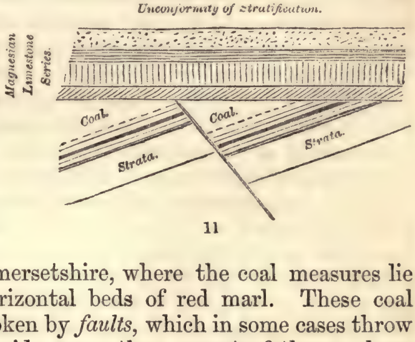


10

the same as that of *z z′* to the lines *b b′*, &c. The contrary appearances, had they occurred, would have been as represented in fig. 10, and such occur in the mining district of Cornwall, together with many other singular phenomena, apparently referable to subterranean disturbance, perhaps complicated with other causes, but which are with difficulty reducible to any simple mode of explanation.

The line of dislocation is generally distinguished by a fissure, which is filled by fragments of the neighbouring rocks, or by basalt, and is then called a *dyke*, or by various sparry and metallic minerals, and is then called a *mineral vein*.

Relative Age of the Dislocation.—The irregular operations by which these disturbances and dislocations were occasioned, seem to have happened at various periods during the formation of the strata. We know, for instance, examples of horizontal strata, as in figure 11, resting upon other highly inclined strata, which must have been forced into their unnatural position before the deposit of the level strata upon them.



11

Such a case occurs in Somersetshire, where the coal measures lie at a steep slope beneath horizontal beds of red marl. These coal measures are also greatly broken by *faults*, which in some cases throw or elevate the beds on one side more than seventy fathoms above

those on the other side. But the beds of red marl above are altogether uninfluenced either by the steepness of the dip or the abruptness of the dislocations. Therefore the convulsions by which these effects were occasioned, happened after the deposit of the coal seams, and before the deposit of the red marl.

At Aberford in Yorkshire, and at many other points along the line of the magnesian limestone between Nottingham and Sunderland, similar examples occur. At Vallus Bottom, near Frome, the mountain limestone is found highly inclined, below level beds of oolite; and the mollusca which lived in the oolitic sea have bored holes into the subjacent limestone.

In such cases the discordance of inclination between the superior and inferior strata is expressed by the term *unconformity*, and the upper rock is said to lie *unconformably* upon the lower.

Principal Epochs of Convulsion.—By pursuing this investigation in different situations, we find that these internal movements or convulsions happened at intervals during the whole period of time occupied in the deposition of the strata. Some of the most prevalent and remarkable cases of dislocation and unconformity are, however, observable: 1, immediately after the deposition of the silurian series; 2, after the accumulation of the coal system; 3, after the deposition of the oolitic rocks; 4, after the deposition of the chalk; and, 5th, one of the most recent probably of all, after the completion of almost all the formations above the chalk. It is not to be supposed that all even of these principal cases of dislocation can be recognized in every country; on the contrary, the subterranean forces appear frequently to have shifted their points of action.

We shall have occasion to show, while speaking of the organic remains, that there is sometimes observed a singular harmony between these periods of extraordinary internal disturbance and the several epochs when the different races of animals and plants came into existence; and it is not unreasonable to suppose, that in this manner it may be hereafter found possible to establish such a relation between the internal and external conditions of the earth, as to afford the greatest assistance towards defining the agencies which have produced changes so extensive and repeated in both.

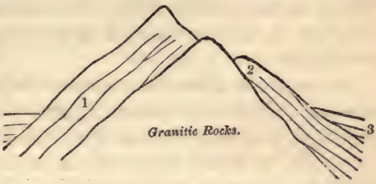
Proximity of Mountains.—At present, restricting ourselves to the phenomena of elevation and disruption of the strata, we shall carry our inductions one step farther, for the purpose of proving what was before announced, viz., that these disturbances were connected with the effects of internal heat.

We shall assume, then, that granitic, and basaltic or trappean rocks, and others exhibiting the same phenomena, were crystallized from a state of igneous fusion, and were, sometimes in a fluid, and sometimes in a solid state, impelled upwards from the interior of the

earth, as analogous substances are now raised fluid through volcanos, or lifted solid by earthquakes.

In proportion as we approach the mountains where the greatest violence was exerted to break up the strata, raise the granite, and inject the basaltic dykes, we find the dislocations increased in number and importance, and the confusion of the stratification more prevalent.

The central nucleus or axis of many mountain districts is a mass, or a series of masses of granite and other unstratified rocks, from which on all hands the strata are found dipping at high angles. In such cases there can be seldom room to doubt that the elevation of the mountain ranges and the disturbance of the strata, was occasioned by the same violence which uplifted the granite.



12 *

The area of granite disclosed between the opposite slopes of strata is indefinite, sometimes very large, sometimes very small, sometimes it is entirely covered over by the rocks which it has uplifted, but not perforated. The general analogy in the composition of mountains, in the strata which surround them, and in the dislocations which abound in their vicinity, prove that one common cause, the force of subterranean fire, has produced all the phenomena in question.

Basaltic rocks frequently, perhaps generally, show themselves in situations removed from the granitic regions, on the flanks of mountains and in lower ground. In numerous instances, basalt fills up the fissure between the elevated and depressed portions of dislocated strata, and as it cannot be doubted that such a fissure would soon have been filled up by other substances, it is clear that the melted basalt was injected nearly at the same time as the dislocation was produced; that is, that both were local effects of disturbed internal heat.

Analogy of Mineral Veins and Trap Dykes.—So great a general analogy prevails between some mineral veins and basaltic dykes, that in almost all hypotheses their origin has been assumed to be the same. Both in the same manner divide the strata; in both the materials are crystalline, generally such as are not known to be producible from water, and arranged according to entirely different laws from those which regulate deposits from water. It seems, besides, almost inconceivable that materials of such various specific gravity and chemical affinities should be either soluble at once in water or capable of being introduced by this process at different times; on the contrary,

* 1. Primary Strata. 2. Primary Strata. 3. Secondary Strata.

all the circumstances agree in claiming for such mineral veins the same origin as basaltic dykes, the igneous origin of which is supported by the strongest possible arguments. We shall, however, discuss the history and origin of mineral veins more at large in the chapter on Plutonic products, and we shall then notice a variety of phenomena concerning them which can with difficulty be explained in the present state of our knowledge of chemistry. That part of the history of mineral veins and metallic substances in general, which is inseparable from the consideration of the rocks in which they occur, will be treated of while speaking of the several strata in succession.

Disruptions of Strata, a part of the general plan of Terrestrial Adaptations.—This elementary statement of the characteristic effects of subterranean convulsions, upon the preconsolidated strata, must not be closed without noticing an important beneficial result of them upon the condition of mankind. The frequent use of the terms convulsions, dislocations, and other such phrases in geological treatises, may, perhaps, lead the inattentive reader to imagine that geologists are of opinion that the laminated crust of the earth, which had been constructed with so great harmony and order, was afterwards subjected to accidental injury, left to the violence of forces not contemplated in its formation, so that the original plan of its fabric was destroyed by unforeseen convulsions. How false a notion is this, and how unjustly would geologists be accused of ignorance in this respect! They know well that without the effects, which are called convulsions and dislocations, the plan of the terrestrial creation would have been incomplete, the earth not adapted, as it is, for the residence of men and the exercise of human intellect, which in all this seeming confusion can discern the progress of an uninterrupted plan, and even trace special provisions in favour of mankind. Whether we regard the mere animal nature of man, or consider him with reference to those glorious endowments which lift him above the brute, and enable him to contemplate the past and anticipate the future, and thus to expand his intellectual existence through all periods and over all subjects, we shall find in the broken stratification of the earth the most remarkable attention to his physical and mental constitution.

Elevation of Continents.—How universal are the benefits which are conferred on commerce and the arts of life, by the variety of substances obtained from the animal kingdom, cannot require to be stated; for without this variety, neither commerce nor the arts of life could exist. Some faint idea of the state of a globe which did not show this variety, may be conceived by viewing the condition of the sandy deserts of Africa, and abstracting from their solitary desolation the assistance rendered by more favourably situated countries.

Now all that variety of mineral products existing in the earth, stored up in that inexhaustible repository to supply many regions through many national revolutions, would have been made in vain, and for ever hidden from the eyes of men, but for these very convulsions and dislocations in the strata. What else has raised our mountains, divided our seas, and given currents to our rivers, and by so doing established upon the globe those varieties of soil, local climate, and other conditions to which the organic wonders of creation are most evidently adapted? What other means have been employed to produce the natural, harmonious, and mutually dependent relation of plants and animals on the land, in the streams, and in the sea? Without these disruptions, the earth would still have been uniformly covered by shallow waters; or if some part rose above it, that must have been a barren waste, or a monotonous surface on which the living wonders of nature, according to the actual plan of creation, could not have appeared. It is, therefore, evident, that as one of the means employed by the Creator in the accomplishment of his works, the agency concerned in producing the actual condition of the terraqueous surface, and thereby regulating the leading phenomena of organic and inorganic nature, is a fit object for the special study of geologists.

Exhibition of Useful Minerals.—It is not only in the elevation of continents, the varying height of mountains, the division of the sea, and similar striking effects, that we see the utility of the combination of subterranean igneous with superficial aqueous agency. Every coal-field in the known world proves distinctly the utility of even the minor dislocations, which in our imperfect language are called "faults" in the strata. The universal effect of these "faults" is to multiply the visible edges of the strata, by bringing them more frequently to the surface, in consequence of which there is, in the first place, the greater chance of discovering the materials of the earth; and, secondly, the greater facility of working them. Other advantages of this kind will immediately suggest themselves to the attentive reader.

But all advantages to commerce and the arts of life sink into nothing when compared with the effect which the human mind experiences from contemplating the monuments of past conditions of the globe, which the uplifting of the bed of the sea, and the dislocations of the strata, have brought to light. All nature is a glorious book, which men are incited to read, in order to know and communicate with its Author, a mirror in which the Almighty and the Infinite is faintly typified in the vast and the diversified; and in this respect geological monuments are distinct, impressive, and, in reference to the earlier epochs, unique. But, if we have been conducted by long labours to some real knowledge of the internal constitution

of the globe, and familiarized with the conception of many revolutions of created beings on its surface, in accordance with a long sequence of mechanical and chemical operations; and if we have thus extended the conviction of the unceasing care and comprehensive benevolence of the Divine Being to the most remote epoch which our limited intellect can reach; all this is owing, in a certain sense, to the convulsive movements originating below the crust of the earth. Let it not, therefore, be supposed, that, because of the contracted scale of the human mind, which can see only in succession what to a greater Intelligence is contemporaneously evident, geologists are obliged to speak of certain phenomena as accidents with reference to others, which are connected therewith by ways unknown to us, that they are so blind as not to see in all the diversified operations of nature, the effects of One predisposing and directing cause.

Internal Structure of Rocks.

Joints in Different Rocks.—All rocks, whether stratified or not, are naturally divided by fissures, passing in various directions, independent of the strata, into masses, which are of different forms in dissimilar rocks, and are accompanied by circumstances deserving more attention than has yet been bestowed upon them. The fissures or planes of parting between these masses are called *joints.* Most frequently their direction is nearly vertical to the planes of stratification, where such exist, and they divide the rock into cubical, rhomboidal, or prismatic portions, blocks, pillars, or columns. It is owing to their various direction and frequency that different rocks assume such characteristic appearances, and may thus be often and readily distinguished when seen at a distance or shadowed in a drawing.

Some rocks have very numerous, approximate, and closed joints, as shale, some kinds of slate, and laminated sandstones; in others, as limestones, the joints are less frequent and more open.

In coarse sandstones they are very irregular, so that quarries of this rock produce blocks of all sizes and forms. From this cause, coarse sandstone rocks show themselves against the sea, in precipitous valleys, or on the brow of hills, in rude and romantic grandeur. The wild scenery of the Peak of Derbyshire, Brimham Crags, and Ingleborough in Yorkshire, derives attractive features from the enormous blocks of millstone grit; and the magnificent rocks which stand upon the hills and overlook the Vale of Wye, are composed of a somewhat similar material.

In clay, vertical joints are numerous, but small and confused, whereas in indurated shale they are of extraordinary length, very straight, and parallel, dividing the rock into rhomboidal masses.

This may be well studied in the shale, which alternates with mountain limestone, at Aldstone Moor in Cumberland. Rhomboidal joints are frequent and very regular in coal.

In limestone the vertical joints are generally regular, and arranged in two sets, which cross at nearly equal distances, and split the beds into equal-sized cuboidal blocks; and thus the mountain limestone is found to be divided into vast pillars, which range in long perpendicular scars down the mining dales of the north of England.

In slate districts, the joints, more numerous and more regular, perhaps, than in any other known rock, have almost universally a tendency to intersect one another at acute and obtuse angles, and thus to dissect whole mountains into a multitude of angular solids, with rhomboidal or triangular faces, which strongly impress upon the beholder the notion of an imperfect crystallization, produced on these argillaceous rocks since their deposition and consolidation, by some agency, such as heat, capable of partially or wholly obliterating the original marks of stratification.

Vertical joints are frequent in granite, and appear to have definite directions. The trihedral and polyhedral vertical prisms of basalt, and some other igneous rocks, coupled with their regular transverse divisions, seem to give us the extreme effect of regularity in the division of rocks by the process of condensation, from the state of igneous or aqueous expansion.

General Cause of Joints and Fissures.—That contraction after partial consolidation of the mass is the general immediate cause of the numerous fissures of rocks, may easily be proved by a variety of facts observed in conglomerates, where pebbles, and in other rocks, where organic remains, are split by the joints. According to the circumstances of the case, this process has produced in basalt, slate, and coal, fissures so regular as to give to the rock a largely crystalline structure, but left in sandstone mere irregular cracks.

From Mr. Gregory Watt's experiments on fused basalt, and some other notices by different authors, we know that a continued application of even moderate heat to a previously solidified body, may be sufficient to develop in it new arrangements of the particles, new crystalline structures, new chemical combinations, and to cause a real transfer of some of the ingredients from one part of the mass to another; from many independent facts it is inferred, as a matter of certainty, that all the strata have locally, and the lower ones perhaps universally, sustained the action of considerable heat, since their first deposition: we seem, therefore, to be possessed of the clue which is eventually to conduct us to a thorough knowledge of the cause of the different structures observable in rocks independent of their stratification.

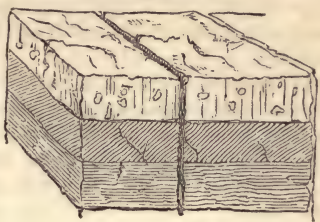
But though heat be taken as the leading cause of these effects, it

is by no means inconsistent to suppose that some other independent agent, as, for example, electricity, might be concerned in modifying the result. From all the recent discoveries in electricity, it appears more and more certain, that this universal agent is excited in every case of disturbance of the chemical or mechanical equilibrium of natural bodies, and it is especially, and very sensibly, excited by unequal distribution of heat. Professor Sedgwick's suggestion with reference to Mr. Fox's electro-magnetic experiments on the mineral veins of Cornwall, that electricity was probably concerned in the original production of those veins along which it now circulates, may be justly extended to the contents of the joints of rocks; in the study of which the writer of these remarks has found abundant reason to believe that the theory of the production of mineral veins is inseparable from that of the joints and fissures, in some of which the metallic substances are deposited.

Direction of Fissures.—In examining with attention a considerable surface of rock, it will be found that amongst the joints are some more open, regular, and continuous than the others, which occasionally stop altogether the cross-joints, themselves ranging uninterruptedly for some hundreds of yards, or even far greater distances. There may be more than one such set of long joints, and, indeed, this is commonly the case, yet, generally, there is one set more commanding than the others, more regular and determined in its direction, more completely dividing the strata from top to bottom, even through very great thicknesses, and through several alternations of strata. For example, there is a peculiar character of joints in each of the principal strata of the mountain limestone series, limestone, sandstone, shale, and also in the sandstones, shales, and coal of a coal district, yet, throughout the whole of Yorkshire, all these rocks are divided by the *master-joints* passing downward through them all in nearly the same direction north by west, and south by east. These master-joints, called *slines*, *backs*, *bords*, &c., are perfectly well known to the workmen, as well as some other very important yet less certain and continuous fissures passing nearly east north-east and west south-west. It is according to such joints that the experienced collier arranges his workings, and the slater and quarryman conduct their excavations. Now, surely nothing can be more certain than the inference, that some very general and long-continued agency, pervading at once the whole mass of these dissimilar and successively deposited strata, was concerned in producing this remarkable constancy of direction in the fissures which divide them all. The deficiency of recorded observations prevents a general development of this important subject by reference to other districts, but it is obvious that a great principle in the construction of the earth is here indicated, which must eventually have an important influence

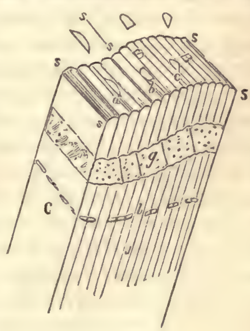
on geological theory. In the meantime we may remark, *first*, that these prevalent directions of north by west and east north-east, are those of the principal *mineral veins* and cross courses in the north of England, and that they are also admitted to be very prevalent in the southern and western mining countries; *secondly*, that these directions are wholly uninfluenced either by the *declination* of the strata, or by the numerous *dislocations* to which they are liable. Whatever be the direction of the dip, how frequent soever the faults, the lines of the great joints are the same. These lines are frequently the cause of particular courses in rivers, long scars on mountain sides, and subterranean channels for water. Faults, and dykes, and mineral veins very frequently pass along them, and there is little doubt that the diligent study of them will be found to throw a new light on some of the most mysterious phenomena of geology.

Division of Strata by Master Joints.



13

Cleavage.—There is yet another structure not common to all rocks nor confined to a given geological age. Though most frequently manifested among the primary strata, it is sometimes observable in others of a later date. This structure is called cleavage, and it consists in a peculiar fissility of the rocks which are affected by it, parallel to a certain plane, which almost always cuts at a considerable angle the plane or curved surfaces of the stratification. In fig. 14, which represents a mass of rocks in which this definite fissility is developed, B B is the surface (curved in this instance) of one bed of the stratification; J is on the plane, here supposed vertical, of a joint; C is one of the planes of cleavage, cutting the surface of stratification B B in *s*-*s*. Parallel to this plane C, the mass of rock here represented is cleavable by art, and is often actually cleft by nature, into very thin and numerous plates, which, when of suitable quality and reduced to proper size, constitute the roofing slate of our houses. The edges of these plates may be traced with care on the vertical surface of the joint J, and the sloping surface of the bed B, and are represented in the figure by fine lines.



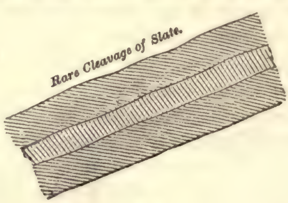
14

It will be observed that these lines do not cross the bed marked *g*. This is supposed to be a hard grit or conglomerate, and such rocks are sometimes only in a slight degree affected by the cleavage, which is perfect above and below them, in fine grained more argillaceous strata. Certain small joints, however, often, and, in other cases, numerous cleavage planes, do cross sandstone beds, and then it is worthy to be observed that the cleavage and joint planes *in these beds* are not parallel to the general cleavage, but meet the surfaces of stratification, as in this figure, at angles more nearly approaching to a right angle. At *l* the cleavage crosses nodular limestone or ironstone, and in these irregular layers *it* becomes irregular, curved, and confused.

On the surfaces of stratification the cleavage structure is frequently traced in narrow interrupted hollows and ridges; these surfaces have in fact been folded, or plaited, or puckered by the force which occasioned the cleavage; and the little folds thus occasioned, are traceable across shells, trilobites, &c., which are thus more or less altered in figure.

On a careful scrutiny of these shells and trilobites, we find that they have been compressed *in one direction*, so that a semicircular shell (orthis), whose hinge line lies parallel to the cleavage edges on B, is found to be altered to the figure *a*; another whose hinge line lies across these edges, assumes the shape of *b*; and a third whose hinge line is oblique to the edges of cleavage becomes distorted as *c*. To make this more clear the letters B B are represented as having undergone the compression in question.

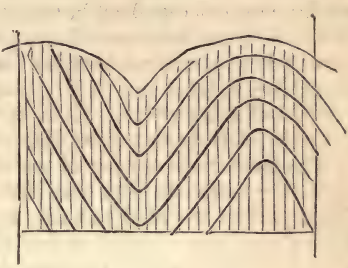
When, as sometimes happens, there are on these surfaces shells and pebbles, too solid and firmly compacted to yield to the cleavage form, *they* are not altered in figure, but the cleavage laminæ in the mass around them are altered a little in direction. It is observable, also, that some change of direction frequently occurs when the cleavage is passing from one bed to another of a different degree of solidity, though in the middle of each bed the cleavage-planes may be parallel. But it also happens, and in some tracts of country, (*e.g.*, the district of Cork), it is a common occurrence, the cleavage planes are not parallel in contiguous beds, of unlike quality, but appear as in fig. 15. The cleavage plane being most oblique to the bedding is the softest and most argillaceous strata.



15

One general relation appears between the stratification and the cleavage—a relation arising from the displacement of the strata by axes of elevation and depression. Parallel to these axes is the "strike"

or horizontal line in the surfaces of the strata; if this be taken on a great scale and the "strike" of the cleavage (similarly defined) be compared with it, the direction of each is found to be the same, or nearly so; in other words the cleavage edges on the surface of the strata are horizontal lines (*s-s* in fig. 14). The direction, then, of the cleavage in a given district is dependent in a general sense on that of the axes of movement in that district; but the *inclination* of the cleavage has no necessary known relation to that of the strata; beyond this, that the dip of the strata being moderate, that of the cleavage is usually greater. In a country where the strata are much undulated, the cleavage may be and mostly is in parallel planes. Thus in fig. 16 the strata are synclinally and anticlinally bent, but the cleavage is vertical, or nearly so.



16

Local Changes of Internal Structure.—We must defer till a later page the theoretical considerations which arise out of these,* and some other valuable data, which have been lately collected by Mr. Sharpe and Mr. Sorby, but though a little out of place we cannot forbear to add here a short notice of facts known in Swisserland, which distinctly prove one of the effects of heat upon common argillaceous shales, to be the alteration of its structure, so as to give a real vertical cleavage to a mass of horizontal laminæ of clay, as well as that induration which belongs to slate. The lias shales of the Alps are so altered by proximity to the igneous rocks of that region, that in several places in and near the Valley of Chamouni, they are commonly mistaken by modern tourists for genuine slates of the primary system, and were always described as such by the older writers. How plainly does this teach us that the joints, cleavages, and other peculiarities of their structure, not produced in rocks by water, nor coeval with their deposition, have been occasioned chiefly by the agency of pressure, molecular rearrangement, or other secondary effect of disturbances generated by subterranean heat. What powerful aid does this generalization give toward explaining many phenomena heretofore despaired of in geology!

Mineral Composition of Strata.

Formations in Water.—Water is both a chemical and a mechanical

* These observations on cleavage are all derived from personal observation, and have been mostly published, in earlier works by the author. Encyclo. Metrop. 1833. Guide to Geology, 1834-6-54. Treatise on Geology, 1853. Brit. Assoc. Report, 1843.

agent, and a receptacle of life. Under different circumstances at certain temperatures, by the help of other ingredients, as acids or alkalies, various mineral substances are dissolved in it. When, by evaporation, loss of heat, or a change in the composition of the liquid, these substances are no longer capable of remaining in solution in it, they separate in a crystallized form, or fall down, and the sediment which they occasion is called a precipitate.

By such processes lime, magnesia, and other earths and metallic oxides, are first dissolved in water, and afterwards separated from it. We find these processes in the present order of nature, chiefly concerned in producing calcareous marls and irregular accumulations of limestone, in lakes and in the course of certain streams and at the mouths of some rivers. So in more ancient times, the most abundant chemical deposit from water was limestone.

The mechanical agency of water is manifest at the present day in removing materials from one place and depositing them in another. Thus pebbles and sand and clay are transported by the tides and by rivers, and accumulated in low situations in regular layers, miniature representations of those thicker strata of the same ingredients, which compose the crust of the earth. And as at the present day some materials are transported farther by water than others, and consequently more rounded by attrition, so the materials of the interior strata are likewise more or less worn and rounded, in proportion to the distance they have travelled and the friction they have suffered.

In many situations chemical and mechanical products are occasioned successively by the same waters, just as in the older strata limestones and sandstones alternately prevail. We see, therefore, that the ancient deposits from water, which form layers several miles thick around a great part of the globe, are not essentially different except in degree, from the lesser deposits now formed beneath the tides from the sea and the streams from the land.

The chemical stratified deposits are principally limestones, composed of carbonates of lime and magnesia, and salt rocks characterized by chloride of sodium. This is not the place to discuss points of theory, and we shall therefore speculate no further at present on the origin of these deposits than to say, that the quantity of lime now held in solution in sea water, is subject to daily waste by the processes of life, and to daily renewal by the afflux of streams from the land. The innumerable tribes of zoophyta, mollusca, and other vertebrata, obtain the carbonate and phosphate of lime necessary for their corals, shells, crusts, &c., from the salts of lime in the sea, and these salts are supplied by currents from the land, which have derived lime from the old calcareous rocks. These rocks are found to be almost wholly composed of shells, corals, crusts, &c., and thus we perceive as a very general fact, that it is less by direct chemical re-

agencies, than by vital energy and the decay of organized fabrics that thick calcareous masses of every age have been and are formed in the sea.

The mechanical deposits, or strata, composed of earthy materials, are distinguished by the coarseness or fineness of the ingredients and by the nature of these ingredients. When the materials are of unequal fineness, and some of them are large, rounded pieces, the rock is called a conglomerate: pieces not so large constitute a sandstone, very fine particles containing some alumina clay. The following scale will convey some notion of the gradations of size in the ingredients of mechanical deposits:—

Very fine particles generally containing 20 to 30 parts of alumina	Clay, marl, shale, and slate.
Mixture of clay and sand	Sandy clay.
Sand with some clay	Argillaceous sandstone.
Small fragments of hard siliceous minerals	Sand, sandstone.
Sandstone including pebbles	Millstone grit.
Large pebbles united by sandstone or clay	Conglomerate or puddingstone.
Pebbles disunited	Gravel.
Stony fragments reunited	Breccia.

Ingredients of Mechanical Strata.—Considered with reference to the *nature* of the ingredients which compose them, mechanical strata form another scale.

Thus gneiss, one of the oldest of these strata, is a compound of the same ingredients as granite—quartz, felspar, and mica; but these minerals, instead of being amalgamated (so to speak) together by crystallization, are accumulated in successive laminæ more or less regular, and more or less soldered together. Some varieties of gneiss, therefore, differ from micaceous sandstone less than is commonly imagined, and often other varieties occur, which have so slight a lamination, and so much of crystallization, as to justly bear the name of granitic gneiss.

Sandstone is generally an aggregate of small fragments, or worn crystals, of quartz, with or without any argillaceous, or calcareous or irony cement in the interstices, with or without any mica in the partings. Sometimes it very evidently contains rolled and broken pieces of crystallized felspar, such as that which fills the Pyramids around Mont Blanc, or the granite of Cumbria and Scotland. There is, therefore, every reason to conclude, that coarse sandstones like the millstone grit, have been derived from the waste of ancient tracts of granite.

Some beds of sandstone at Oban in Argyleshire appear to have been formed from the granular fragments of disintegrated greenstones. Sandstones sometimes extend over vast districts, and during the whole range are characterized by some remarkable mineral ingre-

dient; as for instance, the green sand of England, France, and Swisserland, which is distinguished by the presence of glauconite, a peculiar green mineral, a silicate of iron.

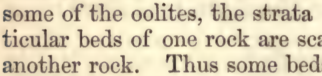
Conglomerates, on the other hand, are generally constituted of fragments from the neighbouring mountains. Thus the red sandstone of the Vosges mountains contains quartz pebbles derived from the slate rocks of the vicinity; the old red conglomerate of England varies in its composition according to its locality; that of Herefordshire contains much quartz, that of Cumberland is filled with pebbles of slate.

Whole Series of Strata.—The whole series of stratified rocks then consists of alternate deposits of limestone, sandstone, and clay, with few layers of coal, rock salt, flint, iron ore, &c. The modes of alternation are different in different parts of the series, and in different situations. Thus the siberian limestones are sometimes enclosed between beds of slate, the carboniferous limestone alternates with sandstone and shale, the lias limestone lies in marly clays, the coralline oolite is enveloped in calcareous sandstone. Generally, the different strata are distinguishable by their mineralogical characters; but not always. When the circumstances of the deposit were nearly similar, as in the accumulation of the carboniferous limestone and some of the oolites, the strata are remarkably alike; and often particular beds of one rock are scarcely to be distinguished from beds of another rock. Thus some beds of lias are scarcely to be known from some calcareous layers connected with the Bath oolite, while other portions of the same rock strongly assimilate to the carboniferous limestone. The old red sandstone and the new red sandstone formations are very much alike; it would be difficult by mere mineralogical methods to discriminate the clays which separate the oolites, and many sandstones of very different epochs are almost undistinguishable. Hence we may infer that nearly the whole series of strata is the result of many repetitions of similar mechanical and chemical agencies operating in similar waters.

Alternation of Beds.—When sets of strata are in contact, as for instance limestone lying upon sandstone, it often happens that while the limestone above, and the sandstone below, are unmixed with other matter, there is a middle set of beds composed of alternate layers of the sandstone and limestone. Thus, let *a* be the coralline oolite of England, and *b* calcareous sandstone beneath; the middle beds *a*′ *a*″ *b*′ *b*″ are alternately oolite and sandstone.

Exchange or alternation of Beds.

Coralline Oolite.



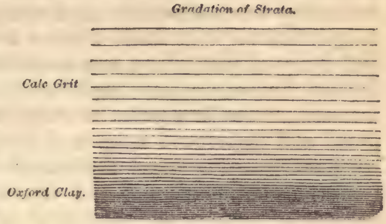
Calcareous Grit.

17

In such a case, therefore, the two strata are said to *exchange beds,*

or to be subject to *alternation* at their junction, and the phenomenon seems to have been occasioned by temporary cessations of the deposit of sandstone during the commencement and progress of the deposit of limestone.

Gradation of Beds.—In other instances, the two strata pass into one another by imperceptible gradation; as for instance, the Oxford clay of the Yorkshire coast graduates into the calcareous grit above so completely, that the bluish colour of the crumbling shale below is shaded off without any hard line into the yellow solid beds of grit above. See fig. 18.



18

In either case it seems quite evident that no considerable break or interval of time happened between the different contiguous deposists, one bed was no sooner formed than another was laid upon it; and by careful study of these phenomena it appears that, bed by bed, and rock after rock, the whole series of strata, even to miles in thickness, were successively and almost unremittingly accumulated, and buried the shells and other organic beings, which were then living in the water, or drifted into it from the land; such are, therefore, the best witnesses of the lapse of time, and of the changing condition of the land and water during the deposition of the strata.

Proportions of Chemical, Vital, and Mechanical Deposits.—Assuming limestones to be of chemical or vital origin, and sandstones, clays, &c. to be mechanical deposits, and putting for the present out of consideration the detached organic remains which so much abound, especially in calcareous strata, we shall be able by comparison of the thickness of the several rocks to present a tolerably accurate notion of the relative proportions of chemical, vital, and mechanical deposits. The greatest obstacles to accuracy exist amongst the hypozoic strata, whose thickness is exceedingly uncertain, and the original condition of the rocks often hardly to be determined at all.

If we take our examples of these strata from the Island of Great Britain, it may, perhaps, be found a sufficient approximation to the ratio now sought to say the mechanical to the chemical deposits of water are:—

In Hypozoic strata	100 to 1.
In Palæozoic strata	20 to 1.
In Mesozoic strata	4 to 1.
In Tertiary strata	10 to 1.

In these comparisons regard is had to the different proportions which prevail in different districts. They would be very different

estimates for tertiary oolites in the Isle of Wight, and in the Basin of London, and for the oolites near Bath and near Whitby.

From this comparison it would appear that the ratio of chemico-vital to mechanical strata is greatest amongst the secondary deposits, and least amongst those of the primary periods; a circumstance on which depend principally the well-marked general characters of the secondary series of rocks. It should, besides, be observed, that calcareous matter very finely divided exists in nearly all the sandstones and shales of that series, and sometimes so abundantly as to change, locally, lias shale into argillaceous limestone, and calcareous grit into arenaceous limestone, or coarse oolite. In secondary strata, the great and prominent masses of limestone almost invariably attract the attention and direct the classification, and thus it happens that while numerous layers of clay and sand pass nearly unobserved, or are merely noticed as *interpolated beds*, almost every calcareous bed has its characteristic local name. The almost universal diffusion of calcareous matter through the mechanical strata of this large class, combined with the greater regularity and persistence of the limestones, generally impresses on the attentive observer a peculiar theoretical notion as to the cause. He soon learns to consider the operations by which sandstones and clays were accumulated as of short duration, and intermitting action, like the periodical floods of a river, or some less regular inundations; while the production of limestone is regarded as the result of one continuous and almost uninterrupted series of chemical changes. This opinion, strengthened by the curious gradations between the calcareous and the sandy or argillaceous laminæ, and by the frequent alternation amongst even their thinnest portions, derives very plausible arguments from the distribution of organic remains through the several strata. In some cases these teach us plainly that sandstones, even of great thickness, were the products of temporary and often of very local floods, which swept down from the land the scattered spoils of the animals and plants then in existence; but, tried by the same tests, the calcareous rocks appear to have been of slower and more equable production, in clearer and more tranquil waters. Is not this exactly in harmony with the present system of natural operations? The pebble beaches of our actual shores and the gravel and sand banks of our shallow seas may be compared with the often narrow and irregular sandstones and conglomerates of every earlier age; the finer clays which fill the broader and deeper hollows of our seas, because such fine sediments are held long in suspension by water, are quite similar in position to the older argillaceous deposits; and our modern coral reefs and the shell beds which accompany them, produced in clear pelagic waters, unmixed with sediments from the land, are in many respects exactly the representations of the old limestones of Wenlock, Bakewell, Calne, and Orford.

CHAPTER III.

ELEMENTARY VIEWS IN PALÆONTOLOGY.

State of Preservation of Organic Remains.

What Organic Remains occur in the Earth.—The fossil remains of ancient plants and animals have been the theme of admiration for the learned and the vulgar in every historical age. The difficulty of understanding how the shells of the sea and the plants of the land could be enclosed in hard rocks, in prodigious abundance and of exquisite beauty, led Plot and Llwyd, and even partially Ray and Lister, together with some continental writers of eminence, to adopt strange hypotheses. Plot advanced the extreme absurdity that these beautiful monuments of the ancient condition of the earth had in fact never been shells or plants, but were merely *lusus naturæ*, deceptive resemblances produced by some plastic power in the interior of the earth. Swift well ridicules this notion of *lusus naturæ* in his Voyage to Brobdignag.

This ridiculous fancy has long since become obsolete, and the "formed stones" dug out of the bowels of the earth are now recognized as the original inhabitants of its primeval land and water.

The differences of condition between them and analogous living objects, the mode of their conservation, the manner of their distribution in the earth, the relative periods of their existence and destruction, constitute a vast and crowded field of research, through which many avenues are already traced toward the secret agencies which were employed in the formation of the earth.

Terrestrial plants abound in certain strata, especially in the coal districts, where the seams of coal are nothing but vast layers of vegetables which grew on the marshy ground, or were swept down into estuaries or lakes, there covered by sand and clay, and changed by chemical decompositions.

Zoophytes, both stony and flexible, many of them belonging to genera now in existence, fill our limestone rocks with their most delicate and beautiful organization; with them lie abundantly columns of crinoidal animals, and crusts and spines of echini.

Molluscous animals are now the most numerous of all the tribes of beings which overspread the bed of the sea, and their shelly coverings are also the most abundant of all the organic fossils.

Of the articulated animals, the most abundant remains are lobsters and crabs, and other crustacea, analogous to existing types; besides trilobites and others to which nothing similar has yet been

found in the modern ocean. Fossil insects are rare; but their number has been much augmented of late years by the researches of Mr. Brodie. The valuable information which they yield concerning the ancient land, now includes the eras of the coal formation, the lias, oolites, wealden, and tertiary strata.

What Portions of the Original Structures are Preserved.—No one acquainted with the structure of the invertebral animals previously mentioned, can view their crusts, shells, and other hard appendages in the fossil state without being struck on the one hand with the wonderful perfection of all their minutest organization, and on the other with the uniform and almost total absence of their soft parts. The bodies found "petrified" in the rocks were for the most part originally durable. Similar substances are now capable of conservation in our cabinets: but the softer animal parts which they protected—the muscles, the viscera, and even the ligaments—have almost uniformly disappeared. Hence it appears a just conclusion that the process of petrification, the substitution of mineral for animal matter, was slow and gradual. There is, however, some further information to be acquired by careful scrutiny. In argillaceous and finely arenaceous strata, we have the ligaments of veneridæ, cardiaceæ, and unionidæ preserved; sometimes in the clay of Christian Malford, and the limestones of Franconia, we find the arms of cephalopoda; in the chert of Tisbury Mr. Charlesworth finds the branchial structure of trigonia.

The same result follows a similar examination of the fossil reliquiæ of vertebral animals. For though we find in tolerable plenty the bones, scales, scuta, and teeth of fishes and reptiles, the soft parts are usually deficient. In the chalk, Dr. Mantell found the swimming bladders of fishes.

The bones of birds are excessively rare in mesozoic deposits; only their footprints remain in older strata. Mammalia occur but rarely in mesozoic strata (Stonesfield, Purbeck), and are only plentiful in the later tertiary rocks.

In what State Embedded.—In consequence of the decay of the softer parts, many of the hard parts of animals are found disjointed and separate. Crusts of lobsters, bivalve shells, vertebral columns, originally bound together by perishable ligaments, are very frequently found in detached portions, precisely as happens to similar objects at the present day; and generally this is all the injury they have sustained. The delicate striæ, sharp spines, and other ornaments, are usually so well preserved, that no one can believe that they were ever removed far from their native haunts. They were, in fact, quietly buried on the bed of the sea; living or dead, entire or decomposed, just as such beings are found at the present day, when by any method the bed of the sea can be examined.

And just as at the present day, where currents run strongly in the sea, shells are worn by friction in the sand, and by beating against one another, and trees carried down by rivers are scattered in fragments; so in certain of the old strata we find similar proofs of rapid currents from the land, and temporary turbulence in the primeval ocean.

All the accidents of imperfection and disunion of parts happened, of course, before the organic bodies were enveloped in the earthy deposits.

Subsequent Changes of Composition.—The changes by which they have been converted to petrifactions did not, probably, commence till after they were thus enclosed.

These changes in the substance of the fossil reliquiæ are different according to the original nature of these bodies, the kind of matter in which they are enveloped, and the other circumstances by which they were surrounded.

We shall make some remarks on the conservation of the principal classes of organic fossils in the different kinds of matter.

In Plants.—Dried vegetable substances may be considered as compounds of carbon, oxygen, and hydrogen, with small and variable proportions of other substances.

Carbon......(C)...........	40 to 55	per cent.
Oxygen,....(O)...........	40 to 50	
Hydrogen, (H)...........	about 5	

The carbon obtained from the carbonic acid of the atmosphere is combined in the living plant with oxygen and hydrogen, in such atomic proportions of these two gases as we find them in their most frequent combination—water. Death releases the elements from this combination; freely exposed to the atmosphere, woody fibre undergoes *eremacausis*,* gives off carbon and water, or the elements of water, and in such a manner that the relative proportion of water to carbon remaining in the wood diminishes, the carbon relatively increases. Two atoms of hydrogen and two of oxygen pass away for every atom of carbon. Thus, if oak wood consists of $C^{36}\ H^{22}\ O^{22}$, it is changed by the process of decay to humus, which consists of $C^{35}\ H^{20}\ O^{20}$; and the change continuing, it becomes $C^{34}\ H^{18}\ O^{18}$; and by continuing the process, we may at last have $C^{25}\ H^{0}\ O^{0}$.

The oxygen and hydrogen seem, in many cases, to have vanished, but the carbon generally remains, and is either almost pure, as in some kinds of anthracitic coal; mixed with some residual oxygen and hydrogen, and containing some special oils and resins, in jet and most coals; mixed with carbonate of lime, as in the remains

* Destruction or decay by slow action of oxygen (ηρεμος, gradual; καυσις, combustion).

of coniferous wood in the lias and oolite, or blended with flint or pyrites in those and other strata. Generally, as might be expected, the vegetable substance is most completely disguised by earthy admixtures in porous strata, such as oolite or sandstone; and, on the other hand, the original carbonaceous skeleton of the plant is preserved with the least change in close, compact materials like clay, shale, or ironstone. This is strikingly exemplified in the coal districts, where ferns and other plants which lie in the shales are changed to bright inflammable coal, while the very same species in coarse gritstone are represented only by a brown, ferruginous stain. Coal is most evidently a product on a large scale, precisely identical with the thin filmy remains of ferns and reeds which accompany it. A vast mass of plants accumulated beneath the ancient sea, or in sea-like lakes, was covered up and buried by successive deposits of sand and clay, and under this heavy pressure, and hermetically sealed, chemical decomposition commenced, or went on, and a new chemical product, coal, was elaborated, which, upon analysis, is found to contain the usual ingredients of vegetables, in proportions no otherwise different than was to be expected from the loss of some of the more volatile parts.

In this respect, coal exhibits many variations. That of Kilkenny, for instance, has only four per cent. of oxygen and hydrogen; Cannel coal has about fifty per cent.; the Kilkenny coal contains ninety-two per cent. of carbon, common coal about seventy per cent. carbon, and thirty per cent. oxygen and hydrogen.

Professor Johnston has published elaborate tables in illustration of this subject, to which attention will be called hereafter. The following extract from Liebig* will suffice for the present :—

	C	H	O
Wood...............	36	22	22
Cannel coal........	24	13	0
Caking coal.......	20	9	0

In Corals, Shells, Crusts—The internal and external hard parts of invertebral animals, zoophytes, mollusca, and articulata, are much allied in composition. They generally contain the same durable and the same perishable elements; carbonate of lime, alone or with a small admixture of phosphate of lime, gives them firmness, and the flexibility which some of them possess is derived from gelatine.

Loss of Colour.—The process of petrification consists in the loss and replacement by a different substance of one or other of these ingredients. The first degree of change which these fossils have experienced, is when the coralline or shell retains not only its exter-

* Organic Chemistry, p. 308, *et seq.*

nal figure and appearance, but even its internal texture, and almost all its original substance. Such specimens look as if obtained from the sea shore in a dead state, with no other apparent loss than that of colour and brilliancy, nor is the colour or polish always lost. This state of conservation may be said almost to characterize the organic remains of the strata above the chalk, but colour-bearing shells do occur in oolite, mountain limestone, and silurian strata.

Loss of Gelatine.—The next step in the process of petrification is illustrated by many shells which lie in the gault and other clays; they have lost their gelatinous portion, and are, in consequence, become light and friable, but have not received into their pores any extraneous earth.

Insinuation of New Matter.—The third variation is occasioned by the gradual substitution of an extraneous substance, as flint or pyrites, into the pores left by the decay or waste of the original body; thus the fibres of wood and sponge, and the plates of corallines and shells, have been changed by little and little into a different substance, which often represents, with most faithful accuracy, the minutest structure of the original. It is evident, therefore, that this great change was accomplished gradually, the new particles taking successively the place of those removed by decomposition.

Analogous Modern Processes.—These processes of decomposition and substitution of new ingredients, which probably commenced at the periods when the several fossils were embedded in the rocks, are to this day continued, and often exhibited with remarkable energy. Those products of modern operations of nature which go under the vague name of recent petrifactions are so various in their character, that a detailed study of them, in relation to their accompanying circumstances, could not fail to furnish data for explaining some of the most remarkable stages in the process of mineralization, to which organic bodies have been exposed in the earth. In proof of this, we shall content ourselves at present with putting in comparison a well-known peculiarity in the mode of conservation of certain fossils, and an instance of the same singularity in recent petrifactions. It is often to be noticed that while the external cell of an ammonite, or the larger part of the spiral cavity of a nerinæa is filled by the coarse matter of the enveloping rock, the closed chambers of the former, and the smallest volutions of the latter, are filled with crystals of calcareous spar. The well-closed shells of productæ, terebratulæ, &c. are often lined internally with calcareous spar, quartz, blende, or even galena, while this never happens, perhaps, to shells whose valves did not fit very exactly. In fossil wood it happens very often that the external parts are merely jet or coal, while the central portions are changed to carbonate of lime; and, in general, all these examples appear to agree in proving that the mineralizing substance

was transferred to its repository in the innermost cells and smallest pores by a kind of secretion, quite through solid septa of shell, and considerable thickness of even dense stone. The recent petrifactions of hazel-wood and nuts, from the alluvium of Ferrybridge in Yorkshire (*Phil. Mag.* 1828), prove that the same remarkable transfer of particles through other substances, with the same elective attraction for these particles possessed by the finest textures and smallest cavities, accompany the ordinary modern aqueous deposits of carbonate of lime. In the alluvium of this place, a certain part of a large collection of hazel-wood and nuts was found mineralized by a subterranean spring from the neighbouring limestone, and it was remarkable that the central woody core of a hazel branch or root was wholly converted to stone, while the bark and outer layers of wood were unchanged, the kernel of the nut was petrified within its brown unaltered membrane, and the internal fibres of the shell within the still woody surfaces.

Dissolution of Shells, Corals, &c.—The fourth condition is exemplified in limestone and sandstone rocks, from which the whole of the substance of shells, corals, &c., has been dissolved and carried away by water. In consequence, a cavity is left in the rock bearing the impression of the exterior of the shell or coral, and in this cavity is a mould or cast of the interior. Thus the "screwstones," as they are called, have been cast or moulded in the cavities of crinoidal columns.

Replacement of Shells, Corals, &c.—The most extreme case of mineralization or petrifaction is produced by a process in addition to that just described, when the cavity left by the removal of the shell or coral is again filled up with crystals of calcareous spar, deposited by solutions filtrating through the stone. Sometimes, only a few crystals connect the inner mould or cast to the exterior impression, but generally, the whole cavity is filled by the spar, which thus represents truly the shape of the original body, but displays no trace whatever of its internal texture.

Dependence of these Changes on the Nature of the Rocks.—There is in general a certain accordance and relation between the condition of organic fossils, and the nature of the rock which encloses them. In the green sand almost all the shells are silicified, in the oolitic rocks many are changed to calcareous spar, in the clays very slight changes have happened to any of the organic remains.

On the other hand, the original nature of the organic substance has very much influenced its mode of conservation. Echinoidal and crinoidal remains are almost invariably converted to a peculiar kind of opaque, calcareous spar, in whatever strata they occur; gryphææ and ostreæ retain their laminæ, inocerami and belemnites their fibres.

Remains of Vertebrata.—We come now to the vertebral division of animals. Their soft portions have most frequently perished, but their teeth, bones, and scales remain, either connected or separated in consequence of the decay of the ligaments, cartilages, &c.

The hardening ingredient of bones is principally phosphate of lime, that of teeth is a mixture of phosphate and carbonate of lime. It is generally the fact that their gelatinous or membranous portion has been diminished, and their earthy admixture increased, by the subterranean chemistry to which they have been subjected, and, in consequence, their specific gravity is much augmented.

Distribution of Organic Remains.

Number of Species.—The researches of modern naturalists have been singularly successful in bringing to light a vast number of new species or supposed original types of organization. The catalogues of living plants and animals have been enormously lengthened in consequence of more rigorous investigations among the smaller tribes. In like manner the number of known organic fossils has been of late years so greatly augmented, that in some departments they nearly equal, and in others exceed the living ranks of creation. In Great Britain alone, 1,500 species of organic remains had been described and figured before the close of 1833; Mr. Morris's catalogue, published in 1843, registers above 5,000; the new edition of this catalogue now passing through the press includes very large additions in all the groups of strata; and it is probable that the numerous tribes of undescribed zoophyta, mollusca, crustacea, and plants, will swell the catalogue to 10,000 species ultimately. An equal number of other kinds adorn the cabinets of continental Europe. Generally speaking, the principal deficiencies in the catalogue of fossils, as compared with that of living organic forms, are found in the aerial and terrestrial races.

Insects, birds, land reptiles, and mammalia are the rarest of fossils. We are, however, not to conclude that the ancient land was uninhabited by those tribes, because we do not find their remains in the strata which were formed on the bed of the ancient sea. Such remains are but rarely carried down and buried beneath modern lakes, and were less likely to be entombed beneath the deposits of the ocean.

Plants.—In the following table, M. Adolphe Brongniart (1839) compared the extinct flora of the ancient world at four several periods with the vegetation which now covers the earth. The general proportion is about 100 living plants to one fossil one.

	First Period.	Second Period.	Third Period.	Fourth Period.	Modern Period.
1. Agamia	4	5	18	13	7·000
2. Cryptogamia cellulosa	—	—	—	2	1·500
3. Cryptogamia vasculosa	222	8	31	6	1·700
4. Phanerogamia gymnospermia ...	—	5	35	20	150
5. Phanerogamia monocotyledonea	16	5	3	25 ?	8·000
6. Phanerogamia dicotyledonea	—	—	—	100 ?	32·000
Indeterminate	22	—	—	—	—
	264	23	87	166	50·350
			540		

The great disproportion between the numbers of fossil and living vegetables will probably not justify the inference that in ancient periods only a few species of plants covered the surface of the earth. Only a small proportion of the vegetable tribes now growing upon the earth are swept down into the sea; comparatively but a very trifling number would be carried there by even the most violent floods; not all of these could be preserved, and therefore the few hundred species of fossil plants are probably only a very small selection from the numbers that really covered the earth. Nevertheless these few relics may be reasonably supposed to have been amongst the most abundant of the plants then in existence, and may be usefully employed in characterizing the several periods of deposition.

Thus it appears that in the most ancient of the four periods defined by M. Brongniart, ending before the deposit of magnesian limestone, the most abundant fossil plants belong to the vascular cryptogamic class, including the natural families, ferns, equisetaceæ, lycopodiaceæ, &c.; that in the third period, which includes the oolitic and cretaceous rocks, cycadeæ are especially numerous; and in the fourth or tertiary period the more complicated dicotyledonous plants prevail, and thus gradually conduct us to the vegetation of the present day.

Zoophytes.—Zoophytes, the first tribe of animals to which we shall advert, are almost entirely marine. The horny spongiadæ and some of the flexible polyparia occur in a fossil state, and the stony corals and the hard echinodermata are exceedingly abundant in nearly all the secondary deposits.

The following table, from which Lamarck's ciliated polypi are excluded, will convey a good general notion of the relative proportions of some groups of recent and fossil zoophyta:—

	British species. Recent.	Fossil.	Recent species described by Lamarck.
Amorphozoa	54	76	147
Lamellated zoantharia	8	280	134
Crinoidea	1	120	3
Astroidea	28	20	76
Echinoidea	12	120	88
	98	616	448

Thus it appears, taking the most conservable groups of zoophyta, that already between six and seven fossil species have been registered for one recent in the British seas. The contrast is greatest in the three great groups of radiated corals, crinoidea, and echinoidea. Compared with the number of recent species known to Lamarck, even the well-known and admired group of corals appear fully twice as numerous in the fossil as in the recent state.

It has often been thought, that the remarkable contrast in the proportions of the fossil and recent zoophytes of Britain might be explained by supposing that the ancient climate was hotter than at present; that, in fact, the former productions of our northern seas were of a tropical character, and this conjecture agrees with the deductions which may be drawn from similar comparisons in the other tribes of animals. The comparative rarity of flexible corallines is not confined to the strata of Britain, it is recognized over all Europe, and seems, at least in part, owing to their more perishable nature.

The contrast is equally striking among the radiaria; and it is especially worthy of remark, that the numerous group of crinoidea, so characteristic of the fossil races of a former world, belongs chiefly to the lower and more ancient members of the stratified rocks.

Passing over the remarkable animals included in Lamarck's class tunicata, which appear to connect the zoophyta with the mollusca, and of which, being mostly perishable (unless we include in them the bryozoa), few or no fossil species are yet recorded, we arrive at the class of conchifera, or bivalve molluscous animals.

Conchifera.—Shells are the most numerous of all the organic treasures buried in the strata; a circumstance which might naturally have been expected from their durable constitution, their vast abundance in the present system of nature, and their aquatic existence. When a lake is drained we find great quantities of shells in the silt which has filled its bed, but the remains of fishes and insects, and even of plants, are rarely met with.

	Described British species. Recent.	Fossil.	Recent species described by Lamarck.
Lamellibranchia—Plagimyona	152	750	800
Mesomyona	19	350	197
Brachiopoda.—Equivalvia	—	20	—
Inequivalvia	5	450	15
	176	1570	1012

The first thing which strikes us on comparing the catalogues of British recent and fossil bivalves, is the far greater absolute number of the extinct species. The proportion is at present nine to one, and when the strata shall have been as thoroughly explored as the shores, the number of our fossil conchifera will probably amount to a thousand, and be to the recent kinds as four to one.

On more minute comparison, we learn that the most remarkable discrepancy in the proportions is found in that singular tribe the brachiopoda, of which above 150 fossil species are already described, while the recent kinds do not exceed five. Perhaps these numbers on both sides will be changed by further discoveries. At least fifty species of spiriferæ, productæ, and terebratulæ remain to be described from the lower calcareous strata of England.

Gasteropoda.—We next arrive at the gasteropodous mollusca with simple univalve shells.

These we shall arrange in groups according to their places of residence: —

	British species. Recent.	British species. Fossil.	Recent species described by Lamarck.
Marine	237	700	1476
Estuary and fresh water	30	70	72
Terrestrial	64	60	274
	331	830	1822

Considerable difficulty is experienced in referring certain fossil shells to their respective recent analogues; and in consequence it is very probable that some of the species above, ranked as estuary and fresh water shells, may deserve a different arrangement.

According to the ordinary, but not quite accurate, notion of their food, gasteropodous mollusca with shells may be ranked thus: —

	British. Recent.	British. Fossil.	General. Recent.
Holostomatous phytophaga	284	580	786
Solenostomatous zoophaga	47	250	1036

Cephalopoda.—We were not till lately aware that there are any fossil shells of the class of pteropodous mollusca, but the remains of the cephalopoda are inconceivably numerous, and far surpass the recent kinds in both variety and magnitude, though we include among the latter all the soft tribes.

	British. Recent.	British. Fossil.
Cephalopoda	14	480

The fossil cephalopoda belong for the most part to genera not yet discovered in a living state.

The fossil species of vertebrated animals are comparatively very few, and some of them, especially fishes, not so perfectly characterized as to admit of much accuracy in their arrangement.

The following summary is chiefly taken from Mr. Morris's catalogue, 1843:—

Fishes	536	British Fossils.
Reptiles	93	
Birds	8	
Mammalia	52	

British Fossil Species.—Considered according to their situations of life, the British organic remains present the following results:—

Terrestrial	Plants	500	and more.
	Shells	60	
	Insects	19	
	Reptiles	15	
	Birds	8	
	Mammalia	52	
Fresh Water and Estuary	Plants	20	
	Shells	120	
	Crustacea	14	
	Fishes	10 ?	
	Reptiles	12 ?	
Marine	Plants	10	
	Zoophyta and Bryozoa	370	
	Radiaria	260	
	Foraminifera	82	
	Shells	2380	
	Crustacea	150	
	Annelida	79	
	Cirripeda	50	
	Fishes	526	
	Reptiles	66	
	Mammalia	?	

European Fossil Species.—Such are the numerical relations resulting from a comparison of the extinct British species of animals and plants on the one hand, with the recent organic beings of Britain, and universal living races of the globe on the other. These relations would doubtless have been considerably modified, had we found it possible to introduce accurately all the European species of fossils. But this task, owing to the still imperfect state of discovery on the subject, but far more to the unhappy confusion of synonyms, is at present hardly practicable. However, not wholly to neglect so important a datum, we shall reprint, from information conveyed to us by Brongniart, Deshayes, Goldfuss, Dalman, and other writers, a numerical statement, drawn up in 1830, of the most remarkable and ascertained European fossils, and put them in comparison with a corresponding estimate, formed at the same time, of the existing species. In each column the numbers are now greatly augmented:—

Remains of Animals.

		In the strata.	Living estimated.
Mammalia, including Cetacea		152	1100
Birds		few	5000
Reptiles		71	2100
Fishes		183	5500
Insects		74	100,000
Crustacea		104	500
Annulosa		104	1000
Cephalopoda		788	100
Pteropoda		5	50 ?
Gasteropoda,	Zoophaga	107	1700
	Phytophaga	773	1408
Conchifera,	Brachiopoda	379	40
	Mesomyona	515	350
	Plagimyona	1132	1400
Tunicata		—	—
Radiaria		278	1000
Polyparia		476	1000
		6036	22190
Plants		540	52000

Number in Different Rocks.—The animal and vegetable fossils are very unequally distributed. For while some rocks are wholly filled with shells, others are absolutely devoid of them. Thus the forest marble and coarse upper beds of Bath oolite are composed of little else than shells, while the sandstones of a whole coal district may contain not one. This does not depend either on the absolute depth from the surface of the earth at which any rock may be found, nor yet upon its relative depth in the series of strata, but it is a circumstance established by experience, and of which some of the causes remain to be determined. The following table exhibits the proportionate number of species of fossils in all the principal strata of Yorkshire, arranged according to their order of superposition :—

	Thickness	No. of fossil Species.	Ratio. Species.		Feet.
Chalk	500	43	1	to	12
Gault of Speeton Kimmeridge clay	150	67 5	1	to	2
Upper calc grit	60	5	1	to	12
Coralline oolite	60	125	2	to	1
Lower calc grit	80	48	1	to	2
Oxford clay	150	36	1	to	4
Kelloway rock	40	60	3	to	2
Cornbrash	5	37	7	to	1
Upper carbonaceous series	200	30	1	to	6
Forest marble slate Bath oolite	30	82	3	to	1
Lower carbonaceous series	500	21	1	to	24

	Thickness.	No. of Fossil Species.	Ratio. Species.		Feet.
Lower oolite	60	91	3	to	2
Lias and marlstone	850	115	1	to	7
New red sandstone	1000	none		——	
Magnesian limestone	215	30	1	to	7
Coal system	3000	100 ?	1	to	30
Mountain limestone	2500	400	1	to	16
Old red sandstone	—	none		——	
Silurian and Cambrian system	6000	20	1	to	300

It is necessary to remark, that the proportions derived from the preceding table would apply only in a general way to the same strata in the south of England, for there the number of organic remains in the chalk is, at least, triple of that in the table, the thickness remaining the same, while the mountain limestone is considerably less rich in fossils. In the counties immediately to the north, the magnesian limestone is far richer in fossils; to the southward it is less rich. Still less is such a table to be viewed as a representative of the results of researches on the continent, for there the new red sandstone formation contains a large suite of organic remains, both vegetable and animal, while neither have yet been found in this rock in England.

Fossil and Recent Species Compared.—We shall now consider what are the kinds of fossils which are contained in these various strata; in other words, in what order of distribution the fossils are arranged in the earth.

A great difference between the present system of nature, and that of which the relics are preserved in the earth, is obvious to any one who considers the relative proportions of the different classes of each. But the most decisive proof of the enormous changes which have happened in this respect is found by a minute comparison of the families, genera, and species. For except in the superficial and comparatively modern accumulations from fresh-water lakes, floods, or tides, and in the most recent of all the strata, scarcely one specimen of all the thousands of existing kinds of plants or animals is found buried in the earth.

The earth contains the records of an ancient system of living nature, which in its great outlines was calculated much like that which we now see in operation; but of which all the details were different. The ancient waters nourished saurians, but they were not our crocodiles; fishes which are generally unlike the finny tribes of the existing era; innumerable shells planned on the same general principles, but executed to different patterns. The plants and the animals of the ancient continents performed the same relative functions as the vegetable and animal races of to-day, and formed part of a similar combination, but, as the circumstances of the globe are now

not the same as then, the forms and structures of its plants and its animals are adapted to the difference.

Successive Eras of Fossil Tribes.—But it must be obvious that to view the whole multitude of extinct animals and vegetables as the products of one ancient era, to confound together all the various different strata which were successively the beds of the ancient seas, would be to destroy the meaning of all the monuments which nature has preserved of the long periods and successive developments through which our planet passed before the completion of its present beautiful arrangement. Each stratum was successively the bed of some ancient ocean or lake, and the remains with which it is filled were the creatures then living in the waters or growing on the land. Each stratum, therefore, belongs to a particular period; it is the museum or repository in which nature has preserved the plants and animals of that period; and the geologist, no longer confined to the mere comparison of recent and extinct species, finds in the earth the proofs of many successive creations and abstractions of life, many systems of nature; and by strict analogy and ample induction looks back through a long vista of revolutions, till the view is lost in the dimness and distance which hide the remote epoch, of which no evidence remains to show that the earth was then inhabited by living creatures.

Terrestrial and Marine Fossils not usually abundant together.—The organic monuments of ancient nature are either of marine, of fresh water, or of terrestrial origin. The corals, and by far the greater number of shells, are marine, certain strata are filled with lacustrine reliquiæ, and others with the spoils of the land.

There is in general the most remarkable and constant distinction and contrast between the rocks which are filled by marine remains, and those which enclose terrestrial productions. Calcareous strata generally are the most richly filled with the spoils of the sea, zoophytic, molluscous, and vertebrated animals; but they rarely contain terrestrial plants. Sandstones and shales, on the other hand, are almost the exclusive repositories of terrestrial plants, but unless they are in some degree calcareous, they more rarely contain marine exuviæ. The reason seems to be that the calcareous strata were deposited slowly and in tranquillity beneath the waters of the sea, and thus enveloped the dead and decaying animals of the ocean; while, on the other hand, the sandstones and shales were more rapidly aggregated, in water too agitated to favour the accumulation of marine reliquiæ. When we find in them few or no traces of land plants, we may perhaps presume that the currents to which they may owe their origin were marine, but when they are charged with ferns, equiseta, and other terrestrial plants, and marked by bands of cyprides, unionidæ, and paludinæ, it seems evident that land-floods contributed to their accumulation.

Oceanic Deposit of Limestone.—The deposition of limestone by chemico-vital precipitation, would probably happen over a large portion of the bed of the sea, and be abundant in proportion to the depth, clearness, and tranquillity of the water; hence the strata of limestone would thicken toward the centre of the oceanic basin. They would also be of more uniform texture, and perhaps of purer composition, in that direction; and since, from accurate observations of the habits of recent marine animals, it appears that they do not multiply so much in the darkness of very deep waters as nearer the shore, we may conclude that fewer marine shells and corals, &c., should be found near the central points of the basins of strata.

How remarkably all these conditions agree in the limestones of the Alps, which appear to have been uplifted from deep water, needs only to be mentioned. There, the rocks corresponding to our oolite, are vastly thicker, more dense, and incomparably poorer in shells, than the same strata toward the borders of the European basin. And if, in proceeding through France to the Alps, we stop to consider the Jura, we shall find its oolites, in respect of thickness and hardness, and quantity of shells, of an intermediate character.

Littoral Deposits of Sandstone, Shale, &c.—On the other hand, sandstones and clays, being mechanical deposits from agitated water, should of course be most abundant along the margins of the ancient sea, and at the mouths of ancient rivers, where the strongest movement of the waters happened. Sandstones are essentially littoral and shallow sea formations, and should be found thickest, and most numerous, and most varied in character, towards the borders of the basin, where the limestones are the thinnest. And as the forces of tides and currents, however powerful, are irregular and limited, the mechanical aggregates which they occasion must be, and in general are, more confined and irregular than the wide chemical deposits of the sea.

This supposition likewise agrees perfectly with what we observe in comparing the oolitic system of the Jura and the Alps with that of northern France and England; for the clays and varied sandstones which diversify this system in the latter countries, and separate it into many distinct groups, are scarcely to be traced in the Alps, and only partially so in the Jura.

Another case in point is furnished by the carboniferous limestone series of England. This limestone in the south of England is so little divided by mechanical strata, that in the Mendip hills, near Bristol, and around the forest of Dean, it is commonly supposed to be one thick rock.

In the north of England it is much and evidently divided, and the number and thickness of the partings of shale and sandstone, and coal, increases continually northwards, while the total thickness of the limestone beds grows less and less. At the same time the

organic remains seem to become, if not more numerous (a point as yet difficult to be determined), certainly more varied in form.

The oolitic system of England presents us with another valuable illustration of the same doctrines.

The oolites of Somersetshire, Gloucestershire, and Lincolnshire form a long range of hills, and are only, and that not universally, divided by partings of clay and marly limestone. But as we advance into Yorkshire we find these spaces augment, and the widening intervals filled up by thick deposits of sandstone, shale, plants, and coal, which predominate so much in the section as almost to obliterate the separated, attenuated, and deteriorated limestones. These, however, are filled perhaps even more than usually with marine exuviæ.

The concretionary or oolitic structure is, perhaps, more decided and constant toward the borders of the strata. It becomes irregular, and at length fails in proportion as the limestone is mixed with earthy impurities. At the extreme northern range of the degraded oolitic system in Sutherland, this structure is nearly lost; it is irregular in the impure limestones of Yorkshire, becomes perfect in the homogeneous strata of Lincolnshire, Gloucestershire, and Somersetshire, assumes more compactness in the Jura, and changes to dense limestone in the Alps.

This is exactly what, *à priori*, would be expected to happen. Amidst the turbulence and admixture of the littoral deposits, a process so similar to crystallization could happen but seldom and unequally, there would be a point at a certain distance from the shore at which the disturbance would prevent regular crystallization, and yet would permit of concretion through the calcareous sediment, and still further the limestone would be more compact and subcrystalline.

Coarse conglomerates, for similar reasons, would be most abundant toward the shores and more local than the finer sandstones and clays, which also would be most likely to contain the remains of plants, as these might be long suspended in the unsettled water, and be transported along with the finer matter.

The distinction here insisted on between conchiferous and phytiferous rocks is so important, that we must, in speaking of the distribution of organic remains in the earth, consider them apart; and while from the former we deduce the ancient condition of the sea at several epochs, the latter will furnish us with analogous data from which to reason on the state of the contemporaneous dry land.

We shall commence with the Marine Fossils, and investigate the manner of their distribution under two general heads:—1st, their relation to the chemical and mineralogical composition of the strata; 2dly, to their relative antiquity.

Analogous Fossils in Similar Rocks.—If the marine fossils are

distributed in the rocks according to their chemical nature, we shall find that *similar rocks contain analogous fossils.* This is certainly the case with respect to the zoophytic animals, for these are almost confined to the calcareous strata. Corals, and various animals of the class radiaria, abound in the silurian limestone, carboniferous limestone, oolites, and chalk.

The remarkable brachiopodous bivalves, as spirifera, producta, pentamerus, terebratula, are also by far most abundant in the calcareous rocks. Gryphææ and smooth oysters are found in the argillaceous strata of the south of England, from the lias upwards to the chalk.

The organic remains of the different limestones of the oolitic formations have very remarkable general analogies. Thus the inferior oolite and the coralline oolite, the fuller's earth rock, and the cornbrash, hold very many closely analogous species. In reasoning on this circumstance, it must be remembered that the distinctions of the oolitic system in England are in some degree local, and probably dependent on the littoral character of the deposits, and that in other parts all these subordinate strata coalesce together into one hardly divisible mass of oolitic limestone. Repetitions of similar groups of fossils indicate the recurrence of similar physical conditions, and teach us very curious truths regarding the old land and sea, and sometimes determine the continuity of river and estuary action through long geological periods.

These are the most remarkable instances of the association of certain organic forms with certain chemical compounds; they are important data to support the opinion that, generally, fossil remains lie near the places where the animals perished. But it is evident that these few analogies by no means establish a general law. On the contrary, when we proceed to consider in this point of view a large number of species, the resemblance between the organic contents of one limestone and those of another of considerably different age, is very slight and shadowy. And as no other strata than the limestones exhibit it in a striking degree, it is evident that some other cause than the chemical composition of their repositories has regulated the inhumation of fossils.

Different Fossils in Strata of Different Age.—That cause, the relative antiquity of the strata, is the subject of our next examination.

That a strict connection does really obtain between the age of a rock and the organic remains which it contains, is made evident by comparing a few well ascertained facts.

The mountain limestone of the north of England contains about 500 species of animal remains; the lias, 120; and the chalk, 50. Now, of all the 670 species contained in the mountain limestone, lias, and chalk, respectively, there is *not one* which is found in two

of these rocks. Neither of these strata contains a single fossil which is found in either of the others. Between the era of the formation of the mountain limestone, and that of the lias, the whole animal population of the sea had been entirely changed; and a similar complete renewal took place before the chalk was deposited. And in the southern parts of England the chalk is covered by other more recent strata, filled with shells and other marine animals, entirely different from all those which lived and died before.

Identical Fossils in Rocks of the Same Age.—Further investigation has demonstrated, that conclusions thus drawn from local researches apply with considerable accuracy in other situations, even at great distances, where the same strata occur. A catalogue of the corals, crinoidal remains, productæ, spiriferæ, terebratulæ, orthoceratites, and trilobites, of the mountain limestone in Yorkshire, may be employed for labelling the fossils collected from the same rock at Namur and Liege; the lias of Whitby contains many of the same ammonites, and the same saurian skeletons as the contemporaneous beds at Lyme, and in Westphalia and Wirtemberg; and the remarkable echini and belemnites of the English chalk accompany that rock through France and Poland to the shores of the Baltic.

The same observations have been made on the other conchiferous strata of England. Each has been traced through the island, and its organic treasures have been explored at every point, and in this manner satisfactory proof has been collected, that along its whole course the fossils which it contains are almost entirely the same. The researches of foreign geologists have demonstrated the truth of this law for the greater portion of the European basin of strata. The figures and descriptions of the English fossils are referred to by the geologists of France, Switzerland, and Germany, and no doubt remains that each extended stratum is the repository of the animals inhabiting the sea at a certain period in the earth's formation, exactly as the earthy bed of the present sea now envelopes the remains of its present corals, shells, echini, and fishes.

General Principle of Smith.—The general principle, therefore, which regulates the distribution of organic remains in the earth may be thus expressed. They are associated according to the periods at which they existed, and they are enclosed in the rocks which were at those times deposited by the water. And as in ancient times, much more than at present, the animal remains over considerable breadths of the bed of the Northern Sea were nearly identical, *strata of the same age contain generally the same fossils.*

Also, because the inhabitants of the ocean were, in the course of time, completely changed, the old races having been extinguished and new ones brought forward to occupy their places, *strata of different ages contain generally different fossils.*

These important propositions form the groundwork of the history of the stratified rocks, and must be ever present in the mind of the modern geologist. The honour of their discovery belongs to Mr. William Smith, an engineer of eminence, who, being employed in 1790 and the following years in surveying collieries, and planning and executing a canal in Somersetshire, established the English system of geology upon the following enunciation:—

"That the strata are laid upon one another in a certain definite order of succession or superposition; may be traced in continuity on the surface of the earth; and may be discriminated when of different ages, and identified when of the same age, by their embedded organic contents."

Gradual Changes in the Races of Organic Being.—By comparing a sufficient number of fossils from all the several strata with analogous living tribes, we discover that those fossils which more nearly resemble the living kinds belong to the strata which were deposited at the least ancient period; as for example, the crag shells of Norfolk and Suffolk, the London clay shells of Hampshire and Highgate, which are all more recent than the chalk.

In these situations we find the families, genera, and even species of shells so similar to recent kinds existing somewhere or other in the ocean, that though they are often very different from the productions of our neighbouring seas, we not the less perceive that they belong to a system very like that now established.

On the other hand, those fossils which present the least resemblance to their successors in the modern system of nature, belong to the older, and especially the oldest of all the conchiferous strata. It is in the silurian and carboniferous limestones that the singular brachiopodous bivalves, producta, spirifera, pentamerus, the remarkable genus orthoceras, the zigzag goniatites, the still but half explained tribes of trilobites, the beautiful crinoidea, chain corals, and favosites, compose a zoological suite, altogether unlike what now exists, a strange and antique order of beings adapted to the primeval deep.

If we estimate the relative periods which intervened between the deposition of any given rocks by the variety and thickness of marine strata which separate them, we shall find that in proportion to the distance of the strata from each other, in proportion to the difference of their ages, is the difference of their zoological contents. Thus the fossils of the mountain limestone are more different from those of the lias than from those of the magnesian limestone. The lias fossils are wholly different from those in the chalk, but partially similar to those in the Bath oolites.

M. Deshayes' Results.—The principle that the difference of the forms of ancient organic life from those of existing nature is directly proportionate to the difference of the epochs of their existence, was

put to a severe and curious test by one of the best conchologists of France, M. Deshayes. Passing over the primary and secondary rocks, in which no plant or animal has yet been found identical with a living species,* he analyzed the tertiary fossils according to their relative antiquity, and obtained the remarkable result, that the lowest and oldest of the tertiary strata contain three and a quarter per cent. of species identical with living types; that a second and less ancient group of these strata holds eighteen per cent. of such analogues; a third more recent group, forty-nine per cent.; and the most recent of all these deposits contains little else than modern species. When we recollect that all these strata are of a date probably anterior to the creation of man and the present races of quadrupeds, the results of M. Deshayes' investigation must be considered as highly valuable data towards forming a just notion of the great antiquity of the stratified rocks, the long periods passed through in their production, and in the accompanying changes of organic life, the gradual nature of these changes, and the correspondence of the general system of nature, at all epochs, even amidst the greatest particular diversity.

Characteristic Fossils.—Some fossils appear to have been in existence only during the deposit of one particular group of strata, as, for example, certain productæ, spiriferæ, trilobites, in the mountain limestone; axinus obscurus, in the magnesian limestone; ammonites Bucklandi, gryphæa incurva, in the lias; ammonites calloviensis in the Kelloway rock; hamites of many kinds in the Gault; ananchytes, spatangi, belemnites mucronatus, in the chalk; rostellaria macroptera in the London clay; fusus contrarius in the crag. These are said to be "characteristic" fossils of the strata, and, in general, very great importance is justly attached to their recognition; but no geologist should permit himself to trust to them exclusively, for they are not always and invariably present, and he may be often called upon to fix the date of a rock by the help of other witnesses. Many fossils are found in more than one rock, and the number of these will probably be much increased by further inquiry. Thus, in the south of England, plagiostoma giganteum occurs in the lias and inferior oolite, terebratula intermedia belongs to the great oolite and cornbrash, pecten lens is found in the cornbrash, Kelloway, and coralline oolite, astacus rostratus and spatangus ovalis range through the Kelloway rock, calcareous grit and coralline oolite of Yorkshire; and mya literata appears in nearly the whole range of conchiferous strata from the marlstone to the coralline oolite inclusive.

These facts entirely overthrow the notion favoured by some geologists, that each rock contains the relics of a distinct creation of animals. They prove, on the contrary, that the changes were not

* Terebratula striatula, fossil in the chalk, has been thought to be identical with the recent shell, T. caput serpentis.

sudden but gradual; and suggest the hope that hereafter, when the laws of the distribution and transference of the existing marine races shall be better understood, and the history of the fossil species more complete, the phenomenon may be satisfactorily explained in accordance with the recognized laws of nature, "constant in her ceaseless change."

Gradations of Deposits and of Fossils Coincident.—It is generally observed that where the series of strata is complete, they are softened as it were one into another by an admixture or alternation of ingredients. Thus, for instance, in Somersetshire, the new red marl and lower lias clays are sometimes softened into one another; and in Yorkshire, the Kelloway rock, Oxford clay, lower calcareous grit, coralline oolite, upper calcareous grit, and Kimmeridge clay are so blended at their junctions, as to render it difficult to draw any hard line of separation. In such cases it commonly happens that several fossils of the lower rock are continued into the next above, and thus the zoological change is as gradual as the mineralogical one. On the contrary, when two strata are separated by a hard and decided line, as, for instance, the coralline oolite and Kimmeridge clay near Oxford, we shall generally be justified in suspecting that the lower stratum is imperfect, in consequence of the removal of its upper beds before the next stratum covered it. In this case the zoological contrast between the two rocks is as decided as the mineralogical one, and keeping in view the Linnæan adage, *natura non facit saltus*, we should be on the look-out for some intermediate beds in other places. Such are described near Weymouth, by Sedgwick; and in Yorkshire, have been named the upper calcareous grit.

The chalk in England contrasts so entirely with the tertiary formations above, that we naturally expect to find in some other country beds of intermediate characters to connect them. These are found at Maestricht, where a sub-cretaceous, granular rock, intermediate in composition between chalk and calcaire grossier, contains many fossils of the chalk, and several which strongly resemble those of the tertiary group.

Probably more complete researches on this point will make known a greater number of such intermediate strata, soften the contrasts between contiguous rocks, and fill up all the blanks in the harmonious system of gradually changing marine deposits, characterized by corresponding transformations of marine exuviæ.

Terrestrial Animals and Plants.—The remains of terrestrial animals embosomed in the earth are very few, and those of plants bear so inconsiderable a proportion to the flora of the present age of the world, as to give us much less information concerning the ancient state of the land, than the marine exuviæ afford of the former condition of the sea.

But as far as they go they confirm in the most satisfactory manner the conclusions drawn from the consideration of marine remains, of the succession of systems of organic nature. The plants which sometimes alternate with, and which overlie in immense variety and abundance the mountain limestone, are a group eminently distinguishable from those which belong to the oolitic coal beds. In the former deposit, lepidodendra, sigillariæ, stigmariæ; in the latter, cycadeæ and zamiæ; and the plants of the strata above the chalk, are still of a different type.

It would thus appear that the same systems of calcareous rocks which contain the most remarkably different suites of zoological remains, likewise enclose in the alternating beds of sandstone and shale plants equally distinct.

As amongst the marine, so amongst the terrestrial remains, those most decidedly unlike the modern productions of nature belong to the most ancient deposits. In the intermediate portion of strata the discrepancy diminishes, and in the most recent rocks, the plants strongly assimilate themselves to the genera and even species which now cover the surface.

We might here examine the conditions of the land and sea as to climate during the several epochs of organic existence, a subject of the greatest curiosity and interest, and for which an immense mass of materials is already collected; but this investigation requires the statement of details which cannot be here with propriety introduced. We must, therefore, postpone the discussion till we come to treat of the strata and their contents in the order of their successive deposition.

We shall then also enter into the history of the fresh water formations which locally diversify the great mass of marine deposits, and contribute to elucidate the character of the ancient land and streams.

CHAPTER IV.

PRIMARY ROCKS.

Granitic Basis of the Crust of the Earth.

General Basis of Plutonic Rocks.—Having now stated general principles, useful alike to the geologist who investigates in the field, and to the student who reads in his closet, we proceed to describe the successive systems of aqueous deposits, beginning with the lowest of all, viz., those which rest upon granite and other crystallized and

unstratified rocks. That there is such a basis of crystallized rocks beneath all the strata, in all countries, cutting off and limiting our observations, and hiding whatever wonders are concealed below, is now universally admitted. The subjacent position of granite is so fully established by observation, that even when portions of it are clearly seen to be laid upon stratified rocks, no doubt is entertained of its having been in every case ejected from its true source below all the strata. But the same observations, which so clearly establish this important law, as certainly overthrow the dogma, once held incontrovertible, that granite is always the oldest of known rocks. They prove to a certainty that granite is of all ages, or, more properly speaking, that its production has really no relation of age to the deposition of any particular set of aqueous strata; but that it has been produced by agencies entirely independent of them, and only locally, and in one sense accidentally, brought into juxtaposition with them. This interesting discovery, from which we learn that the production of granite below the stratified rocks has been continued, perhaps without intermission, during the whole period of the accumulation of the strata, has greatly changed and improved our conceptions of the whole system of geology, and is probably destined to clear still more the horizon of this science. But we must be careful not to be allured by this new light too far from those inferences concerning the age of granite which it so properly qualifies. It does not follow, because some granite is more recent than chalk, that therefore all granite is more recent than gneiss and mica slate. It does not follow, because when in contact with granite veins, gneiss may sometimes assume perhaps even more than even its usual granitoid aspect, that therefore granite is merely fused gneiss, that gneiss and slate are incipient granite, and that common sandstone may in time become gneiss.

But it does follow, as a matter of high probability, independent of further observation, that because granite has been formed at several periods during the deposition of strata, by agencies excited far beneath and independent of them; and because, in some instances fragments, and universally what seem to be the disintegrated ingredients of granite, lie in the oldest strata, that the production of this rock was in progress before any of the strata were deposited; whether those strata now rest upon that old granite or have been forced by subsequent convulsions into contact with newer portions of the same kind of rock.

Whatever theory on the original formation of granite we choose to adopt, it must be allowed that the igneous action to which it owes its birth both preceded and succeeded the aqueous operations, which accumulated the lowest strata now observable.

Primary Strata.

This being admitted, two points of inquiry suggest themselves with respect to the age of the strata which have been called primary. First, are those strata really the *altered deposits* of one long period of aqueous action prior to all the secondary and tertiary strata, or have many repetitions of igneous action *primarized*, to use Mr. Conybeare's remarkable expression, strata of all ages, secondary and tertiary, which happened to be the lowest at the points of action? Secondly, may we believe, as the title of primary seems to imply, that these are the oldest of all the strata, the first that were laid by water upon the consolidated igneous crust of the globe? That these questions should be put at all will probably appear very surprising to those who have drawn all their notions on the subject from books of some date, without attending to the rapid progress of geological opinions.

Primary Strata not to be known only by Mineral Characters, but by their Position.—On the first question we may remark, that it must be allowed that subterranean heat, operating chiefly by the ejection of melted Plutonic rocks, has transformed to a certain degree and limited extent, strata of all ages which were exposed to this action, and thus made the lias shale of Savoy, for example, approximate to the character of clay slate. In such cases, there can be no objection, we conceive, on the part of any geologist to apply the same term to this *change* of the rock, which we may think fit to employ when treating of the analogous *change* presumed upon very good grounds to have affected in more ancient times the strata called primary. We may, therefore, adopt at once Lyell's term of *metamorphic*, and designate by it all those parts of certain aqueous strata which have been transformed in structure or appearance by subterranean heat applied since their deposition. All strata then may become metamorphic under given conditions, and may assume, locally, some of those appearances which belong, perhaps universally, to the primary strata; but are we, therefore, to deny the antiquity of these latter? or to group all such metamorphic strata together as of indefinite age, and merely characterized by proximity to igneous rocks? Surely nothing could be more in contradiction with the principle of classification of strata, the relative antiquity of their deposition. We cannot, therefore, agree to the term *hypogene* of Lyell as applied both to granite and the lowest of the strata usually called primary. When applied to granite it is synonymous with, and may perhaps be preferred to Plutonic; when applied to stratified rocks, its meaning is better conveyed by the term metamorphic, which we shall apply to those portions of all strata, without regard to their age, which are in the altered condition implied.

The true conclusion on the subject of the first inquiry then appears to be, that we are not to assume strata to be of the primary age merely because they appear to have undergone certain changes, analogous to those which gneiss or clay slate have sustained; but we must determine their age by the very same methods as we use in any other case of stratified rocks, viz., by examination of their position relatively to other strata, their organic remains, and their original mineral composition and structure. Examined in this way, there can be no doubt, we conceive, that the use of the term primary, as applied to the extensive series of gneiss and mica slate rocks generally, defining them as a certain mass of strata anterior to most of the palæozoic and all the secondary and tertiary rocks, is perfectly correct, because in all countries where these rocks occur together, the inferiority of their position is well proved; and they have those general analogies of original composition, and those relations to organic remains, which would be satisfactory evidence in every other case. Those who reject the term primary, and yet retain the use of secondary and tertiary, have constructed a series wanting its first term.

Are Primary Strata the Earliest Deposits from Water?—The answer to the second inquiry cannot, perhaps, in the present state of knowledge on the subject, be given with the confidence of assured impartiality. It certainly does not follow that because gneiss, for example, is generally allowed to be the lowest of the stratified groups which we can trace, that there may not be other strata of a totally different nature below it, partially or wholly concealed by Plutonic rocks; still less is it evident that such strata may not have existed, and been subsequently absorbed into the general mass of igneous rocks below. Geologists of eminence appear to think that granite itself is a derivative igneous, from an earlier stratified rock; and that as gneiss is certainly in some respects to be compared to partially fused sandstone, so it may be supposed that while, above, the mass of strata was augmented by additions from water, it was diminished, below, by the transforming action of heat.

Strange as this notion may appear, we certainly are not at present in possession of facts sufficient to wholly disprove it. But neither are there any facts to raise it above the rank of a general speculation grounded on particular and local alterations of stratified rocks. It cannot, therefore, be admitted for want of sufficient evidence, and, perhaps, the following considerations will justify us in rejecting it. The oldest of the primary strata undoubtedly differ from those of later date by the more decided appearances which they present of being derived from the disintegration of pre-existent granitic rocks. The character of the organic remains in the palæozoic portion of the primary strata is in general so remarkably contrasted with those which at present

exist, that, joined to the diminution and final extinction of their numbers as we descend in the series, and the almost perfect identity of their characters over immense geographical areas, we seem really to behold in them the first terms of organization, the earliest records of the establishment of life upon the consolidated crust which overspread the fused matter within the globe.

Conclusions Admitted.—However, without plunging further into premature speculations of this nature, we shall content ourselves with the admitted conclusions.

1. That there is a sequence of age to be traced through all the stratified rocks, which may, therefore, be very justly grouped in any suitable number of successive divisions, as primary, secondary, and tertiary, and that these terms, if convenient, are not improper.

2. That the series of stratified deposits, whether we know their first terms or not, were laid upon a general basis or floor of Plutonic rocks.

3. That the term primitive, whether applied to igneous or to aqueous deposits, must be abandoned, as affirming what is not, and perhaps cannot be proved.

4. The *alterations* of strata, whether by general igneous agency, or by the local contact of melted rocks, being an effect wholly independent, both as to cause and to period, of the deposition of strata, must be treated in connection with the other effects of subterranean heat.

Governed by these considerations, the descriptions in the succeeding part of the treatise will follow the order of time which is marked by the successively deposited strata.

Exceptions to this rule will occasionally occur where it is necessary to notice the changes produced by igneous agency in the condition of the bed of the sea, and other circumstances which influenced the character and extent of the aqueous deposits.

In the following description of strata, we shall retain the general titles of Primary, Secondary, and Tertiary Strata, combining with them a parallel set of names—Hypozoic, Palæozoic, Mesozoic, and Cainozoic strata—and divide them into several systems and formations according to certain properties, or in agreement with their elective associations. The reasons which have determined the mode of arrangement in each case will appear in the history of the several systems.*

* The word "System," which was employed throughout the first edition of this work, 1832, *et seq. ann.* has become the favourite mode of expression for the collective assemblages of strata which have or are assumed to have the requisite synthetic characters for "standing together." (*σμν ιστημι.*)

Range of the Primary Strata.

Study of Mountains.—At all periods in the history of geology, persons of enlarged views have passed over the limited areas of particular islands and kingdoms, and have sought to connect the results of their local inquiries with those drawn from similar researches elsewhere. In this point of view the long chains and insulated groups of mountains become of the highest interest. Those peaks on which the snow rests for ever, whose rocks contain few or no vestiges of life, may be imagined to have stood up in ancient times above the level of the waters, dividing the primeval deep into seas very different from those which now branch off from the ocean. And though this supposition is probably inaccurate, though modern researches render it extremely credible, that, in fact, many of the mountain ranges, far from limiting the ancient sea, and altering the nature of its deposits, were really raised out of its depths at periods comparatively recent, this does not diminish their geological importance. For if by means of this uplifting we are made acquainted with some of the materials which would otherwise have been concealed from the eye of philosophy, these mountain ranges must be studied as the basis of the whole system of geology.

They form, so to speak, the skeleton of the earth, and are the marking features of its topography; their insulated groups characterize kingdoms, their long connected chains divide the races of mankind, and define the geographical limits of the distribution of land animals. To the geologist they have become still more interesting, in consequence of a remarkable general law of their physical structure. For in all climates of the earth, under every conceivable variation of external circumstances, the principal ranges of mountains are everywhere composed of, or at least contain in their axes or nuclei, similar rocks, and those originally the lowest, and in part at least the oldest, with which we are acquainted. By what violence from below they have been uplifted to their present heights, so as to break through and rise from beneath the strata which were superimposed upon them in succession, is a capital question in geology.

These rocks are the primary strata of gneiss, mica schist, slate, and their many associated rocks, the deposits of water, resting upon and often pierced by granite and other crystallized compounds from fusion. An outline of the mountain groups and chains which diversify the face of our planet, seems, therefore, the best foundation for a systematic view of the strata which rest against these rocky barriers.

Relations of Mountain Ranges and Groups.—It has long been the fashion to attempt to establish certain geometrical relations among

the chains of mountains, to refer them to particular parallels and predominant directions, but this labour, unconnected with geological researches, seems to have been very fruitless. Perhaps it would be more correct to say the essence of the geographical relations amongst mountains is irregularity. For though we speak of long-continued chains and belts of mountains, it is very certain, in fact, that to be assembled in groups is the real character of mountain association, and that the chains and belts are nothing but approximated groups. A geological map is in this respect a most valuable instructor; from it we see that, instead of the plains being insulated among the mountains, instead of the upper strata appearing in small contracted patches, like oases in a desert, they spread wide, and flow round the bases of the mountains, as the ocean encircles the islands and continents. Among the few general remarks on this subject, we may observe that the most insulated and many of the loftiest eminences on the surface of the earth are the volcanic summits; the most connected ranges of uniformly high ground are formed by the secondary limestones. Finally, that the general outline of countries is much influenced by the direction of their interior mountains.

European Basin.—The Scandinavian chain, commencing at the North Cape, runs parallel to the coast of Norway, and gives off branches to the east, which pass round the Gulf of Bothnia. The line of the Scandinavian chain may be imagined to cross the sea to Zetland, and from thence to proceed by the Hebridian Isles and the north-western half of Scotland to Ireland, where it is much broken into separate groups in the north, south-east, and south-west of the island. The Isle of Man, the south-western part of Scotland, the Cumbrian group, the broken mountains of Wales, and those of Devon and Cornwall, are so many separate protuberances of the interior rocks of the earth, which, with Bretagne and the north of Spain, compose the interrupted western border of Europe.

The Pyrenees, ranging to the east, may be considered as carrying on the primary range toward the Alps, which hold so long a course from the shores of the Mediterranean in a winding direction to the Danube, and seem to prolong themselves in the inferior ridges of the Carpathians toward the Black Sea and the Caucasus. If, now, we consider Caucasus as continuing the Alpine line round the Caspian Sea to the lofty Paropamisan and Gaur mountains, and from thence turn northward along the summit of drainage, including the Sea of Azof, we come to the Uralian chain, which leads us to Nova Zembla, and thus we find nearly all Europe, and a considerable tract in Asia, enclosed within this irregular circle of primary mountain groups; and it may often hereafter be convenient to speak of this space as the European Basin. It is within this region that the greatest variety of stratification has been observed.

Within this area are the primary elevations of the centre of France, the Ardennes, the Vosges, the Black Forest, the Thuringerwald, the Harz, and the Bohemian Circle; south of it are the Sierras of the Spanish peninsula, Corsica, Sardinia, the Apennines, the Dalmatian ridges, and the mountains of Greece and Mount Hæmus.

Asiatic Basins.—Another basin of about equal extent, but more perfectly defined in its boundaries, and more uniform in its interior composition, is that great Siberian tract which lies to the east of the Uralian, and to the north of the Altaian, Yablonoy, Stanovoy, and Kamschatdale mountains. The vast empire of China and Tartary lying to the south of the Siberian basin, and to the north of the Indian empires, may be considered as a third great but divided basin between the Himalayan and Altaian heights.

The peninsular Indian regions, with their islands stretching toward New Holland, Persia, and Arabia, derive their features from considerable primary mountains directed more parallel to the circles of longitude.

Africa.—The mountains of Africa are long, unconnected ranges. The southern part of Africa is similarly defined by the long ridges of mountains which run from Cape Guardafui in the east, and above the sources of the Congo on the west, to converge about the Cape of Good Hope; while the greatest breadth of this peninsulated continent, from Cape Verde to Cape Guardafui, is coincident with the high mountains of Kong, Donga, and Southern Abyssinia, and the north-western projection is caused by the elevated Atlas.

Principal Line of Mountains.—The interrupted system of primary mountains which extends from the Pyrenees to Behring's Straits may be supposed to continue in the long and magnificent Cordillera parallel to the whole western coasts of America, while the north-eastern shore is parallel to the Alleghany and its northern connections, and between these and the western Cordillera, the vast basin of the Mississippi pours its waters into the Gulf of Mexico. The eastern projections of the coast of South America, which in a certain degree correspond to those of Africa, are owing to lateral extensions from the great western Cordillera.

Though the above enumeration and classification of mountains be extremely imperfect and subject to many objections, it answers the purpose intended, which was to show that the leading features of our continents, their geographical extent and connections, are dependent on the lines of mountainous land, and as these are for the most part constituted of the lowest and oldest stratified rocks, resting on, and uplifted with, granitic compounds, it generally happens, as Mitchell foresaw, that in every country the secondary strata are arranged with reference to the lines of mountains.

Elie de Beaumont's Theory.—An entirely new kind of interest has lately been given to this subject in consequence of the researches of an eminent foreign geologist. Elie de Beaumont, from considerations of some observed accordances between the direction of mountain chains and the geological era of their uplifting, has advanced the hypothesis that these two circumstances are always mutually dependent; and, in consequence, supposes that all ranges of mountains which were uplifted at the same period are parallel to one and the same great circle on the sphere. This is not the place to examine this curious question as fully as it deserves, and we shall, therefore, only mention some of the cases in which this ingenious geologist supposes that the truth of his doctrine may be recognized.

If a great circle be conceived to pass round the earth through Natches and the mouth of the Persian Gulf, and the directions of mountain chains be compared with it, it will appear that the Pyrenees, part of the Apennines, the Dalmatian and Croatian ranges, and part of the Carpathians, are parallel to it. Now, in accordance with some researches of geologists, M. de Beaumont supposes that all these mountain-chains were thrown up at the same geological epoch. Nearly parallel to the same circle are the Alleghanies of North America, the Gauts of India, and the Paropamisan heights; but in all cases very much information is required before we can be asked to admit that distant mountains may have been thrown up at the same epoch.

Another circle may be traced on the sphere parallel to the Alps, from the Valais to Styria, and to this system we may refer the Atlas, the Caucasus, the Balkan, the Himalaya, &c.; and, according to the hypothesis of M. de Beaumont, these must have been all raised at so late a period as since the deposit of the tertiary strata. This subject will again attract our attention.

CHAPTER V.

HYPOZOIC STRATA.

These strata, which have the aspect of being derived from decomposed granitic rocks, with several subordinate and associated strata all devoid of organic remains, constitute, according to the concurring testimony of geological observers, the lowest group of the whole series of Neptunian deposits. From the effects of heat upon these rocks, their natural analogy to granite is sometimes so much heightened, as to cause some uncertainty in distinguishing between them.

The rocks of this whole series might without impropriety be termed *granitoid strata.*

Principal Rocks.—These consist principally of the two following rocks :—

Gneiss, a rock composed of the same mineral ingredients as granite, but laminated and stratified ;

Mica schist, composed generally of quartz and mica, in alternate layers.

With these are associated, and often intermixed,

Quartz rock, generally appearing like a semi-crystalline or imperfectly granular mass of quartz, variously modified by small interspersed quantities of mica, felspar, &c., sometimes more compact, and resembling the quartz of veins, in other examples, mixed with clay slate.

Crystallized limestone, mostly granular.

Serpentine, a magnesian rock generally distinguishable by its softness, smoothness, and bright mottled colours.

Steatite, a still softer and smoother rock than serpentine, generally of whiter colour.

Potstone, a soft, often grey or greenish magnesian rock.

Hornblende schist, a laminated rock of hornblende, variously modified by felspar, mica, and chlorite, generally in alternate laminæ.

Chlorite schist, a rock almost precisely similar to mica schist, with the exception of the difference between chlorite and mica. It is subject to the same contortions as mica schist, and passes like it by insensible gradations to gneiss and clay slate.

Talc schist, mentioned by MacCulloch, is another of the fissile rocks which differ from mica schist only by the substitution of one mineral for another. It is rare.

With respect to the order in which they succeed one another, nothing very definite can be advanced. The greater number of observations concur in assigning to gneiss the lowest place in the system, a conclusion supported by its evident analogy to granite, and in the same general way we may, perhaps, place quartz rock and chlorite schist in the upper part of this system, and next to the clay slate, with which, indeed, they are often associated. Limestone and serpentine are so irregular and peculiar in their occurrence, that though, perhaps, their era is more definite than that of any other of these rocks, they can scarcely be employed to mark a geological date. In some district or other, nearly all these ancient rocks alternate with one another so variously and unequally, that what would be called the oldest rock in one region, may be the youngest in another, and, therefore, it is no wonder if the attempts which have been made to divide the gneiss and mica schist system into several distinct formations have wholly failed. It is not till zoological evi-

dence is brought to bear on the subject that we are able to demonstrate completely the relative age of strata, by distinguishing different deposits and different ages of the same kind of rock.

Gneiss. Its Origin.—That the materials of the mechanically aggregated gneiss rocks, of the whole series of hypozoic strata, in fact, except the calcareous rocks, are derived from the disintegration of more ancient granite and other crystallized compounds, is an opinion which is strongly impressed upon every geologist while examining the composition of gneiss.

The ingredients of gneiss and granite are the same, quartz, felspar, and mica; they are mixed with the like accidents and permutations, and occasional admixture of other minerals, and are subject in both to the same extreme variation of size. But these rocks differ in the most essential point of view under which they can be compared, viz., the mode of arrangement among their constituent masses. The ingredients of granite are so connected together by contemporaneous, or nearly contemporaneous crystallization, that one substance penetrates and is united into another, and we are compelled to conclude that they were accumulated together not in distinct pieces ready formed, but that they actually never had a separate existence as solids until their different properties were developed by crystallization from a fused mass.

On the contrary, gneiss well characterized suggests almost always, by some degree of imperfection of the edges and angles of the quartz and felspar, and much more decidedly by the laminar arrangement of the mica, and consequent minute stratification of the rock, that its materials, ready made and crystallized, were brought together and arranged by some mechanical agent, principally influenced by gravitation, in fact by water. Could any doubt remain on this subject after a sufficient examination of gneiss strata, in all their gradations from a rock resembling granite to a fine grained fissile mass, hardly distinguishable from clay slate, it would surely be at once removed by comparing them with a suite of sandstones, many of which, like gneiss, are composed of granitic detritus, and strongly allied to it in structure, but not having undergone metamorphosis, show clearly that they were aggregated by water.

In a great majority of instances, gneiss rocks immediately follow granite; being then composed of the materials of that rock which had suffered the least degree of waste and abrasion, it is no wonder that on several occasions it should strongly resemble its parent. And if we allow, what may probably be true, that the heat of the granitic nucleus was then sufficient in some places materially to affect the consolidation of the strata on the bed of the sea, we shall perceive another cause why the most ancient mechanical strata approach in character to the Plutonic rocks.

Though the disintegrated materials of granite compose almost universally the substance of gneiss, fragments of granite are most rarely discovered in it.* This circumstance, combined with its numerous laminæ and crystalline aspect, seems to indicate that the aggregation of gneiss happened without any great degree of turbulence or lateral motion in the water. It may, perhaps, lead us to suppose that in those early periods the fluctuating temperature of the bed of the sea contributed sometimes to accelerate the aqueous decomposition of the granite, and afterwards at intervals to harden its stratified materials into gneiss.

Stratification of Gneiss.—Gneiss beds are of extremely various thickness, and the laminæ of which they consist are subject to such extraordinary curvatures, that it is often very difficult to trace them.

Where other rocks alternate with gneiss, as hornblende, slate, quartz rock, limestone, or mica slate, the stratification is rendered very evident, but otherwise the beds are less regular, and are often discontinuous, as in micaceous sandstones and in argillaceous slates.

The contortions of the laminæ of gneiss are observed to be most numerous and surprising, where, as frequently happens, veins of granite, quartz, or felspar divide this rock. These veins cross the laminæ at various angles, and generally cause some peculiar twists along their sides; they not unfrequently insinuate themselves between the laminæ, and in this case, when thick and extensive, may be mistaken for alternating strata. It is probable that many cases of supposed alternation between gneiss and granite may be thus explained, and that in other cases the rock called granite may be really a coarsely granular gneiss, whose particles have been very little moved by water, or unusually affected by subsequent application of heat.

Minerals.—Gneiss being one of the most extensive stratified rocks, is a rich repository of minerals, both in the new and the old world. Garnets frequently, zircon, beryl, disthene, epidote, tourmaline, rutile, oxide of tin, oxide of iron, sulphuret of molybdena, more rarely, are disseminated in its laminæ. The veins of quartz, calcareous spar, carbonate of iron, and sulphate of barytes, which divide it, contain the sulphurets of lead, copper, and zinc, native silver, tin, &c. in Sweden, Germany, and Brazil; and many other minerals occur in the calcareous strata which alternate with, or are enveloped by, the strata of gneiss.

Rocks Associated with Gneiss.—Gneiss alternates with granite in the Riesengebirge and in Quito, and in some cases graduates into the character of granite, as on the southern declivity of the Titlis

* MacCulloch says that in certain varieties of *mica schist*, fragments of granite, of quartz rock, and of limestone, are embedded in it. Perhaps he may not always have been careful to avoid admitting conglomerates among mica schist and gneiss.

and Jungfrau (the age of this gneiss, however, may be more recent); more frequently it exchanges beds with mica schist, hornblende schist, and granular limestone and clay slate. These rocks are sometimes in such small quantity as merely to mark lines of division in the mass of gneiss, but at other times they swell out to great thickness. The limestone beds in particular are remarkably local and irregular in their occurrence, and instead of extending, like the more recent calcareous strata, through large tracts of country, appear in the form of large lenticular masses, enveloped on every side by the predominant rocks of gneiss. The term *subordinate*, on a great scale, is not improperly applied to these lenticular rocks, though in local geology their occasional great extent and comparative regularity may entitle them to be classed under an independent title. Thus Charpentier arranges the granular limestone of the Pyrenees.

By the substitution of hornblende for mica, gneiss gradually changes to hornblende schist; the loss of its felspar approximates it to mica schist, the diminution of its mica produces the resemblance of quartz rock. A finely granular slate, with more evidence than usually appears of watery friction among the particles, almost transforms gneiss to sandstone (Dalnacardoch); a more minute admixture of its ingredients, with a predominance of chlorite, gives it the aspect of argillaceous slate. In all these cases great caution is required, and its geological relations should always be consulted before deciding on the name of this Protean rock. These gradations happen most frequently at the junctions and alternations of the several rocks.

Mica Schist. Its Origin.—Mica schist, like gneiss, appears to have derived its ingredients from the destruction of granitic rocks; but it contains but little felspar. May we conjecture that a variety of this mineral, easily acted on by ordinary agents, was itself decomposed during the disintegration of the granite, and mostly dissolved, leaving the quartz and the mica to be arranged by the water in the alternate layers which render this rock so remarkable?

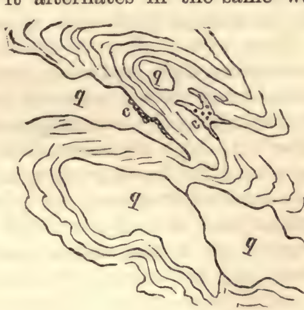
The lamination of this rock is subject to much unevenness, in consequence of the irregular size and arrangement of the pieces of quartz, and the undulations thus occasioned on the micaceous surfaces, are often further modified by interspersed garnets, for these appear to have pushed aside the other ingredients. Besides this minute inequality, the laminæ of mica slate are liable to the same contortions and curvatures as those of gneiss; the same difficulty often occurs in tracing its beds, similar and very numerous veins of quartz traverse and mingle with its layers, and when in contact with granite it is locally penetrated by similar granite veins. Small cavities lined with crystals appear among the most contorted parts.

The sketches presented below, (figs. 19, 20,) were taken with care

from the mica schist near the anticlinal axis of these beds, which crosses the upper part of Loch Lomond. On a *great scale*, the laminations of gneiss and mica schist are sufficiently parallel to give the idea of disturbed surfaces of deposition; on a *small scale*, by close examination, innumerable centres of local forces, producing minute, recurring, and anastomozing curvatures appear. These *minute flexuosities* are clearly due, not to general or external pressure of the whole mass, but to the mechanical displacements effected in the mass by the generation of new minerals (as garnet), the aggregation of others (as quartz, or felspar, or both). Thus the mica and chlorite which generally meet the surfaces of lamination, appear to have been shouldered about, without being fused, twisted in their structural planes, and subject to that curious minute folding which is often observed as one of the effects of cleavage structure in delicate and pliable shells, in slates, for which the term "creep" was used by the author in 1843. See small figure 20 *a*.

Minerals.—Various minerals are similarly disseminated through it, as garnet, emerald, beryl, disthene, tourmaline, felspar, epidote, hornblende, columbium, molybdena, rutile, oxide of tin, wolfram, oxide of iron, grey cobalt, native gold. Its metallic veins are of the same nature as those in gneiss: it alternates in the same way with quartz rock and the older slates, and encloses similar deposits of limestones. It seems, therefore, almost superfluous to say, that the line of rigid distinction between the mica schist and gneiss can only be drawn in the closet. Yet, in fact, on a great scale, the two rocks retain their typical characters over large tracts of country, and must be considered apart.

19



20

20 *a*

Quartz Rock.—Quartz rock, in the greater number of instances, seems a more recent deposit than mica schist and gneiss, though, indeed, by an easy change of its composition, it becomes nearly identical with them. This circumstance, combined with the internal evidence of texture, seems to decide the question of the origin of quartz rock, and to prove that, however altered by subsequent igneous action, it is originally a Neptunian and mechanical deposit. The degree of compactness which it exhibits varies through a large range, in some cases approaching the loose granular character of sandstone,* in others the density of the quartz of veins. In this latter case it seems that the mass is composed of fragments so firmly united as to suggest the idea of their having been soldered or fused together since their deposition from water. Perhaps, also, in some cases, what has been considered as quartz rock may be really an expanded or overlying vein.

Minerals.—In South America, this rock is the repository of many rich ores and metals. Native gold is found in Brazil in a stratified rock of quartz, and micaceous iron ore, which is suspected by M. Eschwege to be the original repository of diamonds, and appears to be intimately related to quartz rock. The flexible quartz of the same country is a granular rock with drusy cavities containing topaz and amethyst. (Brongniart.)

Crystalline Limestone. Its Origin.—Crystalline limestone is in general observed to be stratified, frequently to alternate with gneiss and mica schist, and sometimes to retain argillaceous partings; it is therefore a Neptunian deposit. Its frequent high state of granular or saccharoid crystallization may perhaps be due to changes operated since its deposition, and partly occasioned by the action of subterranean heat, of course more sensible in the lower than in the upper calcareous deposits.

It is difficult to imagine that such a rock could be formed by crystallization from water, often in laminæ exceedingly thin and regular, and alternating with evidently mechanical deposits. That the calcareous matter of many rocks, at first precipitated in sediment, has been since arranged in crystalline and concretionary masses, is certain. Thus the oolitic structure, thus the crystalline cement of the Lincolnshire oolites, has been occasioned. These effects, it is now known from artificial trials and from observations in nature, are more decisive when heat and pressure operate upon the particles. By this combination, the earthy sediment of chalk is condensed into crystalline limestone.

* Some of the quartz rocks of Scotland and Anglesea have a conglomeriticc haracter. In Garveloch, Von Dechen noticed rounded masses of granite, quartz, and corneous limestone embedded in a basis of clay slate, passing to quartz or mica schist. Mr. Sharpe cautions us that some of the quartz rocks of MacCulloch are of later date. (Phil. Trans. 1851.)

The deposits of crystalline limestone, whether distinctly stratified or not, are in general detached and limited, and so entirely enveloped in the strata of gneiss and mica slate, as to compose but a subordinate member of those extended formations. This fact appears to indicate that in the earliest periods of Neptunian operations, the precipitation of calcareous matter was occasioned by agencies of a more local and limited nature than those which produced the broad strata of lias, oolite, and chalk.

May we imagine that the accumulation of these nucular or lenticular masses was determined by local developments of subterranean heat, which, directly, by change of temperature, or by intermediate chemical agencies, might render the calcareous matter insoluble? However we may seek to explain it, the fact is undoubted, that during the aggregation of the gneiss and mica slate systems, a large quantity of calcareous sediment was deposited, not in one uniformly extended stratum, but at scattered points, and in unequal quantity. And this irregularity of deposition continues to be observed in an inferior degree in the limestones of the lower palæozoic system, which are often lenticular, but above this point, where the influence of the internal heat must be supposed less intense and more equally diffused, the calcareous strata become at once more abundant, more regular, and more uniformly extensive.

Minerals.—Though primary limestone be, in fact, a simple rock, its aspect admits of many variations from the unequal admixture of other mineral substances. Of these the most frequent are mica, talc, and steatite, the latter of which often communicates a green or mottled colour to the whole rock. Crystals of augite (Tiree), garnets, and felspar (Col. de Bonhomme), occur in it in some places, and tremolite and argillaceous slate lie upon its laminæ. It sometimes assumes a brecciated character, as if composed of limestone fragments, and more rarely contains fragments of rocks of the gneiss and mica slate system.

It is the fruitful source of statuary and architectural marble, contains a great variety of minerals, and is locally traversed by veins of quartz, felspar, and granite, and by veins of cobalt, galena, iron.

Contains no Organic Remains.—The limestone associated with the truly ancient gneiss and mica slate is destitute of organic remains. The gneiss and mica system may therefore be considered as *hypozoic*, or beneath the strata which contain reliquiæ of *palæozoic* life. But this distinction, when applied to such vast thicknesses of rock devoid of these remains, and variously alternating, acquires its just meaning only by adding other considerations which give it a theoretical value. It has been said that if we suppose the crystalline limestones devoid of organic remains, to have derived their peculiar texture from changes subsequent to their deposition, under the influ-

ence of subterraneous heat, it is possible that the absence of organic remains may be often a consequence of this change. This is possible; at the same time it will be shown by circumstances, hereafter to be mentioned concerning the slate system above, that there are strong grounds for believing that what we now call *hypozoic* strata were really formed when no organic life was manifested on the globe.

To conclude this discussion, we may collect in a small compass the possible speculations of the origin of the gniess and mica schist.

1. That it is merely laminated or foliated granite, a rock of fusion; the foliation being due to collection of the mica into certain laminæ, whether this be owing to an unexplained mode of segregation, or to internal motion in the mass during consolidation. This speculation fails, because of its being wholly inapplicable to the quartzitic, and chloritic, and talc schists, which certainly form a part of the gneissite and micacite system.

2. That it is an originally semicrystalline, or confusedly crystalline deposit from thermic solution in water, a process by which many vein stones have been thought to be formed. This has been too little examined to allow of our pronouncing an absolute negative. Somewhat in favour of it may be quoted, the minute and complicated contortions of the laminæ—analogous to what takes place in the deposits of steam boilers—and apparently against it is the great prevalence of mica, which it is difficult to establish as originating from water. Mica, however, under the name of "peach," occurs in some of the Cornish veins, whose origin from mere dry heat is sometimes hard to conceive.

3. That the gneissic foliation is the original, or the remains of the original lamination imparted to the mass by the successive accumulation of its particles under water, and altered by subsequent action of heat. This heat is sufficient in some cases to modify the external texture, almost to obliterate the structure, and thus to reconvert the gneiss to granite, in other cases enough to solder the grains of quartz, felspar, and mica, and to generate new minerals of easier fusion—as garnet—and in other cases merely to impart a superior degree of coherence (as in quartzite). This view has the advantage of reconciling the diversity of the gneissic and schistose beds, with probable differences of mechanical origin and degrees of applied heat, and takes account of the general truth, that the foliation of the whole gneissite and micacite series is parallel to the great axis of movement, while the excessive abundance of minute flexures, the occurrence of many cavities, and the frequency of intrusive quartz veins, are observed on and near to the summits of the arches of the laminæ.

4. That the irregular foliation of gneiss is in no degree original, but a case of superposed structure, produced in these granular rocks

by the same general cause as that to which the regular cleavage of the fine grained clay slates is due; that it is not stratification, due to successive aggregation of the parts, but a new crystalline arrangement of the particles. It appears a strong objection to this view, that the two phenomena here referred to one cause, have the opposite qualities of regularity and irregularity, *on a small scale*, while the conformity to one axis, which in this respect the formation of gneiss manifests with the cleavage of clay slate *on a large scale*, is unquestionably also shown by stratification. On the whole, we conclude in favour of the third hypothesis as most in harmony with the facts generally.

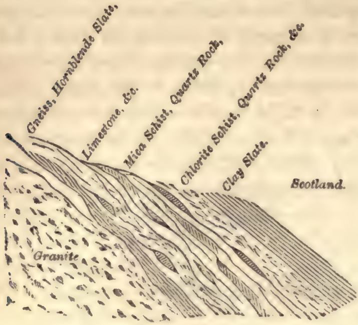
Districts of Gneiss and Mica Schist.

In England, &c.—The extent of countries occupied by old gneiss and mica schist with their associated rocks is enormous; and there are few districts of sufficient area where granite appears, without being followed by these deposits. But the order of their succession, and their relative thickness, are very uncertain. In some districts, gneiss, in others mica slate, in others quartz rock, make up the whole visible system, and are immediately succeeded by clay slates. There are even cases where the whole system is wanting, and large areas of granite are immediately invested by clay slates and limestones containing organic remains. In England, for example, gneiss and mica schist, and primary limestone, and quartz rocks, are almost unknown; but in Ireland, and especially in Scotland, they are abundant, and include among them many gradations, chlorite slate, talc slate, hornblende slate, &c.

In Cornwall and Wales the granitic rocks are almost universally succeeded by modifications of clay slate, Anglesea only exhibiting a quartzo-micaceous group below all the Cambrian slates; and though in Cumberland the granite of the river Caldew is indeed covered by rocks, having the character of gneiss, mica schist, dark hornblende slate, (provincially called whintin,) and chiastolite slate, their area and thickness are inconsiderable, and the latter rock soon changes to clay slate. At a place called Martindale, at the eastern foot of Caldbeck Fells, is a fine-grained variety of gneiss in very thin, straight laminæ. Granite veins are rarely known to divide any of the rocks of this region, except on a small scale between Skiddaw and Saddlebank. Gneiss occurs, sometimes exchanging its mica for hornblende, on the east flanks of the southern parts of the Malvern hills, much intermixed with trap. It may be regarded as older than the silurians of that region.

The general order of succession among the older primary strata

in Scotland may be represented in a diagram as in fig. 21, but it must be remembered that all the terms of the series are seldom coexistent in the same vicinity.



21

Gneiss in Scotland.—Gneiss is abundant in Scotland, particularly in the northern and western parts, and being exceedingly variable in composition, is very often undistinguishable from mica schist, under which head apparently M. Boué has preferred to class many of its varieties.

Gneiss constitutes almost the whole mass of Iona, Tiree, Coll, Rona, and the Hebrides, and enters largely into the composition of the Zetland Isles, which are in some measure to be viewed as a prolongation of the Hebridian group, as the Orkneys appear to be an extension of the eastern rocks of Caithness, Housa, Burra, Whalsay, Out Skerries, and Yell, and the western parts of Fetlar and Unst, and part of the mainland of Zetland, are gneiss. The remainder of the mainland is principally mica slate, and the two rocks are partially separated from each other by an interrupted deposit of limestone. The gneiss is often porphyritic, as in Unst; at Hagrasattervoe* it appears to contain masses of granite as well as to be traversed by veins of syenite and talcose granite. Kaolin is derived from it in the mainland and in Fetlar. Gneiss exists likewise in the Orkneys around the granite of Stromness.†

In the Hebrides, this rock changes often from the typical mixture of quartz, felspar, and mica, by the substitution of talcose minerals and hornblende for mica, by the omission of the quartz, and by the interlamination of argillaceous schist. Some varieties are extremely slaty, and suffer rapid decomposition; others approach nearer to granite, and present rude and naked surfaces and precipitous faces, with few brooks and little alluvium. The direction of the strata in the Hebrides is north-east and south-west, but the inclination is obscured by frequent contortions. These, in MacCulloch's opinion, are most frequent in the vicinity of the granitic veins which divide all the gneiss rocks, except those which are associated with clay slate. The drawing which he presents of the contorted laminæ of gneiss and hornblende slate, in connection with ramifying granite veins, near Cape Wrath, seems to justify his views. The laminæ of gneiss

* Hibbert, Edin. Phil. Jour. vol. ii.

† Boué, Geologie de l'Eccose.

are often peculiarly bent, or apparently dislocated along the line of the veins; and sometimes masses of this rock are curiously enveloped in their substance.

The veins are not often filled with granite of the ordinary kind, but with a compound rock, in which felspar highly predominates, so as to form in several places (Harris, South Uist, Rona, and Coll,) a real graphic granite, which in Coll contains garnets. Veins of quartz occasionally metalliferous, likewise traverse the gneiss of Coll and Tiree. Garnet, rose quartz, zircon, hornblende, epidote, fluor spar, iron pyrites, and sulphuret of molybdena, occur in the gneiss.

Mica schist is not abundant in the Hebrides, but in Rona, Coll, and Tiree, it alternates universally with the gneiss.

Gneiss occurs in many places, as round the granitic mountains of Bræmar and Lachin y gair, at Kincardine in Ross-shire, and other points in the extreme north of Scotland; but the most abundant and interesting deposit adjoins to the granite of Strontain.

It forms the beautiful and picturesque region around Loch Sunart, which strongly resembles the Trosachs of Loch Katrine, being equally rich in wood, and remarkable for intricate confusion of rugged surface.

The curvatures to which its laminæ are here subject are very numerous and extraordinary; veins of quartz, felspar, and granite are extremely common, garnets abound in it at certain points, and the metalliferous veins with carbonate of strontain, harmotome and remarkable calcareous spar are highly interesting. On the eastern side it is bounded by porphyritic masses, but in other directions appears to be overlaid by mica schist, to which its composition approximates.

Mica Schist in Scotland.—But the principal part of the Highlands is occupied by the mica schist formation, whose strata range with more or less regularity north-east and south-west, notwithstanding the interruption to their continuity by the unstratified rocks of the Bræmar mountains, and the groups of Ben Cruachan and Ben Nevis.

The south-eastern limit of this vast deposit is the line of the foot of the Grampians from the Forth of Clyde to Stonehaven. Deposits of red sandstone, lias, and a carboniferous part of the oolites border the eastern coast from the River Spey to Duncansby Head, and extend through the Orkneys; rocks of igneous origin, associated with the preceding, mostly occupy St. Kilda, Skye, Rum, Eigg, Mull, parts of Ardnamurchan and Morven. Within these limits, and with the exception of irregular masses of igneous rocks and of gneiss, the whole of the vast space belongs to the mica slate system, with its included quartz rocks, limestones, serpentines, potstones, its associated hornblende and talcose slates, and its overlying clay slates.

The mountains of this system of rocks are formed into little groups separated by deep valleys and long lakes, and their bases being usually and thickly covered with birch, underwood, and sometimes with forests of oak, while their summits rise often more than 3000 feet above the lakes, the beauty of the scenery is admirable. Scenes, indeed, of a truly alpine character are very rare in Scotland, and, perhaps, nowhere occur except in the Cuchullin mountains of Skye, and the granite peaks of Arran; but very grand and imposing effects are produced by the combination of narrow woody defiles, precipitous slopes, and rocky crested summits. The general outline of the mountains is pyramidal, but this form, elegant at a distance, is broken on a near survey by fantastic projections, and bare cliffs, and by numerous channels, which after storms are changed into a multitude of waterfalls. The valleys destitute of lakes are usually wild and barren, and covered with scattered rocks.

Several of the most remarkable valleys in the Highlands follow the ranges of the strata, as for example, the extraordinary valley of lakes which are united by the Caledonian Canal, whose highest summit is but 90 feet above the sea, the valley of the Spey, Glen Tilt, Loch Tay, Loch Long, Loch Fyne, Loch Awe. M. Boué observes, that the longitudinal valleys are remarkably narrow, as if mere slits in the country, while the numerous transverse valleys are in general more widely expanded.

One of the most interesting valleys in Scotland is Glen Roy, rendered classical by MacCulloch's description in the *Geological Transactions*. Two narrow, parallel, contiguous terraces, perfectly level and continuous along the whole length of the glen, mark the higher part of its bordering slopes with a singular and most surprising character, the effect of ancient local operations of level water. It has been with probability conjectured that these lines are the traces of the ancient margin of the sea, left uninjured during a subsequent elevation of the whole country to the extent, perhaps, of 1500 feet. By the natives of these wild regions they have been traditionally supposed to be the works of man in the fabulous ages.

As might be expected, the forms of the mountains, and especially the shape of their summits, is considerably characteristic of the kind of rock which constitutes them. Compare, for instance, the irregular head and broken slopes of the Cobler and other mountains of mica slate, with the smoother sides and less angulated chloritic top of Ben Lomond, and the conical summits of quartz on Benan, Schehallion, and the Paps of Jura.

Neither are the features of the valleys and waterfalls independent of the nature of the rocks which they traverse. The unequal hardness of mica slate, in particular, is often evident in the rapid streams, by singular hollows and pits in their course, and deep cavities under

the cascades. A waterfall near Loch Earn Head exhibits this feature very remarkably.

The most important point of view under which mica slate can be considered mineralogically, is the well-known variation and entire change of character to which it is subjected by alteration in the proportions and permutation in the nature of its ingredients. It cannot be thought surprising that a rock, constituted probably of the detritus of many granitic aggregates, should be extremely various in its composition. M. Boué is of opinion that we may observe on a great scale these variations to be dependent on the general principle, that in proportion to its antiquity or proximity to granite, mica schist becomes more felspathic and more quartzose, in fact, more like gneiss; and on the contrary, that in proportion as it recedes from the fundamental rocks, it becomes more talcose, more chloritic, more argillaceous, in fact, more like clay slate.

Examples of gneiss-like mica slate are found in Glen Tilt, Dalnacardoch, and many other points of the Blair Atholl country, near Tyndrum, and sparingly around the granite mountains of Arran.

In some specimens (Glen Roy) it appears composed of little else than mica folded and twisted round garnet crystals, in other cases (Ben Nevis) the garnets form almost distinct layers. In some cases (Glen Roy) the white mica and quartz form very smooth and attenuated laminæ, like those of cleavage, in others (Trosachs, Loch Earn) the quartz is in thick irregular plates, which mark one of the gradations to quartz rock.

Quartz Rock in Scotland.—Quartz rocks and quartzose mica slates are seen in the north of Scotland, in Moidart, along Loch Sheil and Loch Eil, and the eastern side of Loch Linnhe. Above the granite of Glen Tilt, quartz rocks abound in Ben y gloe, and several mountains round the granite of Braemar, and may be well studied in the valley of the Bruar, near Blair. They reappear in Mount Alexander, and on the sides of Loch Rannoch, constitute the pyramidal summit of Schehallion, and on the borders of the granitic desert of Rannoch Heath are traversed by granitic and porphyritic veins. Farther west the Island of Jura is distinguished by the obtusely conical quartzose mountains called the Paps of Jura, and the same rocks extend into Isla. Dr. Hibbert has described the quartz rocks in Zetland.

Talcose Slates in Scotland.—Talcose and chloritic slates, holding an intermediate mineralogical character between clay slates and mica schists, also for the most part occupy the intermediate geological position. They may be well studied on the banks of Loch Lomond and Loch Fyne, and several points on the south slope of the Grampians, where they are often rich in quartz, and remarkable for minute undulations and greater contortions. Chlorite slate is also found in

the Long Island, and in Fetlar and Unst. The mica schist of the Highlands very generally contains garnets, which are of various size and occur under different circumstances. It seems difficult to explain the very common association of garnets with mica schist and gneiss, except by admitting that this mineral is one of the effects of heat applied to those rocks since their deposition.

Hornblende Slate in Scotland.—Hornblende rocks, especially hornblende slate, occur in various combinations with mica slate. Hornblende is seen plentifully in Glen Tilt, and is much traversed by granite veins, on both sides of the Pass of Killicrankie, south of Schehallion, north of Ben More, in the upper part of Loch Lomond, and under Ben Cruachan.

Serpentine in Scotland.—Serpentine, a rock whose geological relations are very imperfectly understood, occurs in Scotland at many places, accompanied generally with talc or steatite, and diallage rock. It is said by Boué to be most frequently placed among the upper beds of talcose slate, though occurrences of serpentine, in small quantities, accompany the limestones of Iona, Glen Tilt, Harris, and Tiree.* On the south side of the Grampians it occurs only at Cortachie, on the North Esk, but through the north of Scotland its localities are more scattered. (Near Drimnadrochit, near Inverness.) The serpentine of Portsoy, said to be employed in some of the apartments at Versailles, forms "three vertical beds," one of them enclosed between hornblende rocks, another between hornblende rocks and primary limestone, and the third between quartzose talc slate and mica slate, which is covered by beds of limestone, hornblende slate, and talc slate, and the junction of all these rocks is softened by a mutual exchange of ingredients. In Scalpa, an irregular, highly inclined bed, one hundred yards thick, of serpentine traverses the gneiss promontory of the lighthouse, and exhibits at its boundaries against the gneiss abundance of hornblende crystals, layers of talc slate, and a sublaminated structure. It contains steatite, asbestus, &c. The granite veins here observed traverse both the gneiss and its included serpentine, and in the latter rock talc is superadded to the ingredients of the vein.

Serpentine exists also in Lewis, and occurs in Zetland in considerable abundance and beauty, both in the Mainland, in Fetlar, and at Brassa Sound in Unst, where it contains chromate of iron in sufficient abundance to be of considerable value in commerce.

Potstone is found in Glen Elg, opposite to Skye, and in the serpentine of Scalpa. But the most remarkable rock of this kind is found at St. Catherine's, near Inverary, on the opposite side of Loch Fyne. It is imperfectly slaty, and has been employed in the erec-

* MacCulloch.

tion of the mansion of the Duke of Argyll. Boué also adds as localities, the districts of Strathearn and Breadalbane.

Primary Limestone in Scotland.—Primary limestone. One of the most important of the subordinate or interrupted rocks which diversify the vast surfaces of gneiss and mica slate in Scotland remains to be noticed. So much has been before said on the composition of this rock, that we shall here dwell chiefly on the question of the relative ages of the different deposits. In the absence of organic remains, we can only examine the associated rocks, and the texture of the limestone itself. The white marbles of Iona are found in a system of rocks by some referred to mica slate, but considered by MacCulloch to be gneiss. The variously coloured marble of Tiree, with its embedded augite and hornblende, lies in a system of alternating gneiss and mica slate. That of Glen Tilt, characterized by its accompanying tremolites, lies in a quartzose mica slate, associated with hornblende slate. Notwithstanding the want of agreement in character between the limestones, and the more important differences between the rocks which enclose them, some geologists think these limestones are of the same age.

Boué, following up the notices of MacCulloch, traces the line of the Glen Tilt limestones to the east and to the west. In the western direction they proceed from Gow's bridge, crossing the hills at Lude, and tending toward the south, pass through the Glen of Fincastle and across the valley of the Tumel. It is conjectured that limestone of the same range continues by Mount Alexander, and the base of Schehallion, from whence it proceeds through Glen Lyon to the side of Loch Tay, at the foot of Ben Lawers, reappears in Crien Larich, at the entry of Strath Fillan to the west of East Tarbet, in Knapdale, and the head of the valley of Croe.

Eastward from Glen Tilt, this limestone is traced in the course of the North Esk, and in the valley of the Dee, near Braemar, &c.

So extensive a range of limestone rocks in the direction of the strata of mica slate, seems, indeed, to require little additional evidence of its being throughout a nearly contemporaneous deposit. The limestones on Loch Laggan and Loch Eil in Inverness, and at numerous other points in Aberdeenshire, are referred by Boué to the same era.

Second Range of Primary Limestone.—A second range of limestones, lying chiefly in argillaceous and chloritic varieties of mica slate, is considered by the same author to be of more recent origin. The points are near Blairgowrie, at the foot of Ben Vorlich, on the north side of Loch Earn, Balquhidder, Inverary, Knapdale, and Lorn, and the limestones of Balahulish, Cairndow, and Dalmally, as well as those which run from Boharm to Bamff, are classed with these more recent limestones.

Perhaps the relations between all these points may not have been correctly ascertained. In every attempt to trace a contemporaneous line through the older strata devoid of organic remains, much must be trusted to vague analogies; but there seems excellent reasons for admitting that these calcareous rocks, like those which are more perfectly traced among the newer strata, were the produce of a few definite periods, and not mere irregular formations having no relation to each other in respect of time.

The granite of the Isle of Man is followed by very little gneiss and mica slate, much Cambrian or Silurian schist (from which the mica schist and gneiss are metamorphic), and quartz rock. The mica slate is traversed by veins of quartz and schorl.*

North of Ireland.—The older strata of the north of Ireland may be considered as in part a prolongation of those of Scotland; thus the extensive formation of mica slate in Londonderry and Donegal is on the line of the chain of the Grampians, continued through Jura and Isla; and the clay slate ridges which border the Mourne mountains, run in the direction of the Mull of Galloway and the clay slate chain of the south of Scotland, while between these two systems of slates are carboniferous limestone, red sandstone, and other strata of newer origin, corresponding to those which separate the analogous chains in Scotland.

The mica slate rocks are principally of the talcose varieties without garnets, but producing hornblende. Deposits of laminated primary limestone of different colours, containing talc, quartz, hornblende, or pyrites, with veins of quartz, chlorite, and calcareous spar, occur in the mica slate, in many parts of Antrim and Londonderry. Hornblende slate likewise forms distinct beds in the mica slate of this region, and felspar porphyry is described as interposed under the same circumstances.†

South of Ireland.—In the south-eastern part of Ireland, granite is extensively seen, and mica slate forms two ranges along its eastern and western boundary, and wherever it occurs is in direct contact with the granite. On the eastern side of the granite it runs in a narrow course north-east and south-west, dipping steeply south-east, and consists of alternate layers of mica and quartz of extremely variable thickness. On the eastern brow of Rochetown Hill, mica slate runs into a natural hollow of the granite, still retaining the north-east and south-west direction of its strata. On Maulin Hill, it is singularly and fantastically contorted on the small scale. There is a prolongation of the body of mica slate at the head of Glenmacanass, gradually narrowed in its western progress, and constituting a wedge-like mass, inserted into the body of the granite, and enclosing a seeming bed of granite six to ten yards in width, besides

* Henslow, in Geol. Trans. Cumming's Isle of Man. † Berger in Geol. Trans.

irregular masses of granite incorporated with the slate. In the same vicinity, greenish, sectile, talc slate lies embedded in the mica slate, and is used for various purposes of architecture and sculpture.

In Glenmalur occurs a remarkable instance of decided alternation of granite and mica slate, under circumstances very favourable for its display. In a space of 208 fathoms, no less than five distinct alternations of granitic beds, with as many layers of mica slate, are clearly traced, and several of these beds are compound, or really made up of similar alternations of granite and mica slate, or quartz and mica slate. The great mass of granite is below, and the great mass of mica slate above, constituting the hill called Lugduff. Grenatite abounds in this slate.

Similar alternations occur in other neighbouring places, making a total thickness of one-third of a mile, and the whole system ranges north-east and south-west, and dips south-east. On the north-east they probably abut, and terminate against the granite. The mica slate on the summit of Lugnaquilla is likewise interstratified with granite. Clay slate bounds it on the east, and at length coming into contact with the granite cuts off its further progress to the south.

On the western side of the granite the mica slate is still less extensive. It is found to enclose beds and elliptical masses of granite in Glenismaule; and it is mentioned that a granite vein, four to eight inches wide, ranging 25° north of west, cuts off the mass of alternating strata, without occasioning any displacement. In the same valley are two distinct beds of compact greenstone porphyry in the mica slate, one four feet wide, the other two feet. Andalusite abounds in the mica slate of this country, and greenstones of various kinds alternate with it.

The frequency of the phenomenon of alternation between mica slate and granite is a singular feature in the geology of this part of Ireland, for the full display of which we are indebted to Mr. Weaver.*

In Brittany.—The tract of old rocks in the north-western part of France is one of the most extensive in Europe. The granite, generally the most elevated, is separated from the secondary strata by a system of gneiss and mica slate, and by another system, into which they pass almost indefinitely, of lower palæozoic clay slates. In the departments of Calvados and La Manche, these two systems appear as zones around the granite, the gneiss being within the clay slate. Quartz rocks of blue colour, and pegmatites with tourmaline, are associated with them, and veins of quartz and granite traverse them.†

In the Pyrenees.—The granitic masses of the narrow chain of the Pyrenees having been uplifted in much confusion, are very irregularly

Geol. Trans., vol. v. † De Caumont, Geol. du Cavaldos

bordered; in several places they are overlaid by gneiss and mica slate, but generally by the latter series. Charpentier, a disciple of Werner, thinks the gneiss of the mountains which border the valley of Soulan so intimately connected by gradation and alternation with the subjacent granite, as to be necessarily united therewith into one formation. In many instances gneiss and granite are described as alternating in very thin layers. In other cases, vast blocks of micaceous gneiss of 100 cubic fathoms' bulk are buried at intervals in granite, always preserving one constant relative position or direction of strata. These are thought by Charpentier to be of contemporaneous origin with the granite, which passes into them at the sides, and thus interlaminates the gneiss.

Mica slate, in the same manner, is intercalated with granite in a great many places, and quartz and felspar bands occur in the granite. In many places in the Pyrenees the 'granite' contains beds of stratified granular limestone, (such as in other districts lies in the gneiss,) with graphite, talc, fluor spar, mica, hornblende, &c.

The more modern view of these phenomena is that they are quite consistent with the doctrine that granite is an igneous, but gneiss and mica slate originally aqueous rocks, and that in some cases what is called granite, is in fact gneiss with the aspect of granite, derived from a more than usual condensation and greater effect of heat. Boué, Dufrenoy, and other writers, have proved beyond a doubt the powerful action of heat along the Pyrenean chain, as evinced not only by the usual subcrystalline character of the clay slates, but also by the metamorphism of the chalk into the characters of primary limestone, with abundance of metallic and granitic veins at the line of junction of the altered stratified and the igneous rock. The age of the eruption of granite along this chain is, by observations of Dufrenoy, determined to be, at least in part, posterior to the chalk.

It is extremely probable that the same kind of explanation will be found to apply equally to the alternation of granite and slates in Ireland and Cornwall, and to the alternations of porphyry and slate in Cornwall, North Wales, and Cumbria. It is to be remembered, however, that the igneous theory, as it has been termed, does not by any means require that all these beds of seeming granite should be pronounced to be altered gneiss, nor that the beds of porphyry should be considered as altered clay slate. Alternating igneous and aqueous action is perfectly intelligible, and exemplified in modern operations of nature; but certainly in many cases, both in Cornwall and Cumbria, it appears the more correct view to suppose a gradual and partial *rearrangement* of the materials of the rock, through the long action of heat. This would well agree with the indefinite boundaries of the porphyries of Cornwall and Cumbria, which often pass by insensible modifications into ordinary slate.

In Central France.—The great central plateau of old rocks in France from which the Loire, Vienne, Dordogne, &c. take their source, is chiefly a granitic and porphyritic tract, surrounded by oolitic and carboniferous rocks, but clay slates and gneiss rocks appear in the valley of the Vienne, and occupy a large part of the southern boundary. Near Limoges are alternating beds of granite and gneiss, and some subordinate beds of pegmatite and hornblende rock; the gneiss passes by one variation to granite, by another to mica slate. The ranges of the strata near Limoges are north-east and south-west, and they are crossed by decomposing elvan courses to north north-east. Tin veins occur near Vaulry in gneiss as well as in granite. Towards the borders of the district the gneiss becomes less granitic, more associated with hornblende slate, and encloses deposits of micaceous limestone. Serpentine lies in this gneiss in many places, and M. Cordier appears disposed to refer them all to one contemporaneous, though interrupted deposit. The pegmatites and kaolins of St. Yrieux, which have resulted from them by decomposition, form numerous veins and strings in the gneiss and hornblende slates, which sometimes intercalate themselves between the laminæ. Quartz rock of bluish colour exists likewise in the Black Mountain and elsewhere. Oxidulated iron abounds at many points in the gneiss; galena, phosphate of lead, carbonate of copper, antimony, and hæmatite, are the products of the veins.*

The most remarkable alterations of secondary limestones take place, according to Dufrenoy, along the line of junction with the granitic and porphyritic masses. Thus the lias and oolite become metamorphic, and are traversed by metalliferous veins, as in Cornwall and Brittany, where the slates are metalliferous principally in the same situation.

Other Localities in Europe.—After these details of the circumstances attendant on gneiss and mica slate at so many interesting points, we shall only add some general observations on the range and extent of this system of rocks in other countries. Gneiss and mica slate in small quantity occur in the Vosges, and gneiss more abundantly in the Black Forest.

The long irregular chain of the Alps contains a vast quantity of gneiss and mica slate, variously extended around the talcose granite cores of Mount Blanc and St. Gothard, from the Mediterranean almost to the Danube. The age of this gneiss may be matter of doubt.

Deeply buried beneath the valley of the Danube, gneiss and mica slate do not reappear around the granitic origin of the Carpathians. Their place is supplied in this chain by a vast deposit of clay slate.

The primary mountains which encircle Bohemia are, on all the southern half, granite. Gneiss and mica slate are superadded on the

* Desnoyers

west, and the former rock in particular abounds in the Erzgebirge. The Riesengebirge granite is bordered on the north by gneiss, on the south and east by mica slate, and these rocks are associated with granite in the range which divides the drainage of the Oder and the Elbe.

These rocks are most extensively spread over the northern parts of Europe, from Copenhagen round the Gulf of Bothnia, along the Uralian chain toward the Caspian Sea and the Caucasus.

In America.—In America, Humboldt describes gneiss as less abundant along the high chains of the Andes than along the inferior mountains of Caracas, in Oronoko, Brazil, New Spain. It is occasionally auriferous, and contains micaceous, primary limestone. The most considerable masses of mica slate mentioned by this distinguished traveller are those of the Cordillera of the shore of Venezuela. This formation in the Andes is less rare on the north than on the south of the Equator. Nowhere, perhaps, is the total suppression of mica slate formations more frequent than in the Cordilleras of Mexico and South America.

The eastern primary range of North America passes through the United States from the St. Lawrence to the Mississippi in a direction nearly parallel to the coast, and generally 100 miles distant from it.

The prevailing and characteristic rock is a syenitic gneiss, in which the divisional planes are obscure, and frequently evanescent, when the rock is undistinguishable from the syenite which forms part of this great metamorphic group. Gneiss retains in general its place next the granite, which, however, is in small extent; it is often succeeded by hornblendic, micaceous, and talcose schist, and granular, sometimes dolomitic limestone, seldom pure enough for fine statuary. It is traversed by granite veins at Haddam, in Connecticut.

This is the principal metalliferous band in the United States, yielding magnetic iron ore in veins and beds, near Lake Champlain, in New York, New Jersey, Pennsylvania, and Maryland; on the southern side of Lake Superior, in the vicinity of Montreal, in Wisconsin, in the Iron Mountain and Pilot Knob in Missouri, and in Arkansas. Copper ore occurs in Lake Huron, and on the northern shore of Lake Superior. Lead ore lies in these rocks in northern New York; lead and copper in Pennsylvania; zinc or red oxide, mixed with franklinite, occurs in New Jersey; phosphate of lime has been found in New York and New Jersey; kaolin marble, building stone, firestones, hones, steatite, plumbago, and many fine crystallized minerals, as apatite, zircon, spinelle, sphene, augite, tourmaline, may be added to this list.

The range of the rocks is from the high country north of the St. Lawrence, westward to the sources of the Mississippi, and south-

ward along the elevated ports of Maine, New Hampshire, New York, New Jersey, Pennsylvania, Maryland, Virginia, and North Carolina, to Alabama, with isolated belts in Missouri, Arkansas, and Texas.*

CHAPTER VI.

LOWER PALÆOZOIC STRATA.

For the purpose of clearly unfolding the relations of the various argillaceous, arenaceous, conglomeritic and calcareous rocks which comprise the vast and variable series of the lower palæozoic strata, it is desirable to fix our attention upon districts where the variety of the rocks is considerable, the section ample, and the order of succession perfectly known. We commence with the districts of the English Lakes, and the picturesque valleys of Wales.

As early as 1818, Mr. Jonathan Otley of Keswick had arrived at a general classification of the slate district of the lakes in three divisions. In 1821, Smith used this classification; in 1822 I discovered upper silurian fossils, as they would now be called, near Kirkby Lonsdale.† In that year Professor Sedgwick obtained his best fossils from the same neighbourhood, under the guidance of Smith,‡ and in many succeeding years of toil he has followed out his admirable observations with unconquerable patience and perseverance, and has, in fact, mastered all the difficulties of detail, in the beds above the green slate, which no one can over-estimate. The following is a transcript of his latest classification §:—

6. Group from Benson Knot, south of Kendal, through Kirkby Moor to the Lune, called Kirkby Moor group..................	*c.* Tilestone and red calcareous flagstone. *b.* Grits and coarse flagstone, without transverse cleavage. *a.* Coarse slates, &c., with occasional transverse cleavage, north of Kendal Fell, forming a passage into the lower group.
5. Ireleth slate group.	*d.* Coarse striped slates alternating with beds of gritstone, much contorted and of great thickness. *c.* Great or Upper Ireleth slate; no traces of Aymestry limestone. *b.* Ireleth limestone in a discontinuous and concretionary form. *a.* Lower Ireleth slate.
4. Coniston grit........ (Transition group.)	Coarse hard gritstone, conglomerate, and thin bands of slate. Collectively of great thickness.

* Lyell in Report on Industrial Exhibition of New York, 1854.
Trans. of Geol. Society, 1829. ‡ See "Letters" in Wordsworth's Survey of the Lakes.
§ Trans. of the British Association, Report for 1853.

3. Coniston limestone group	*b.* Coniston flagstone and calcareous slate.
	a. Coniston limestone and calcareous slate.
2. Green slate and porphyry	Great beds of roofing-slate, &c., alternating indefinitely with porphyry, trappean conglomerate, trap-shale *shaalstein*, &c., collectively of enormous thickness.*
1. Skiddaw slate.......	*c.* Masses of gritstone, rarely of coarse texture.
	b. Mountain masses of black slate, with veins of quartz, not effervescing with acids.
	a. Beds of porphyritic chiastolite slate, passing (when near the granite) into chiastolite rock, and beds which are entirely metamorphoic.

Nearly all that is valuable in the geology of the slate system of Wales is due to Henslow's description of Anglesea, Sedgwick's labours in Snowdonia, and all its intricate dependencies, Murchison's detailed investigation of the south-east portion of the district from Shrewsbury to the mouth of the Towy, and the arduous labours of the geological survey. In the north-western district, the general inferiority of position of the chloritic and micaceous schists to the whole clay slate system of Wales is clearly proved; the true place of the Snowdonian shells fixed in the parallel of Bala and Llandilo, the extent and effects of subterranean convulsion and intrusion of igneous rocks, very fully pointed out. The south-east border, described by Murchison, fortunately presents a series of phenomena, deficient or not clearly separated in the great slate district of Cumbria—a vast number of organic remains, lying in distinct groups, a series of distinct members of the formations which these fossils appear to characterize, limestones of different ages which clear up the difficulty, always felt previously in fixing the true relations of the limestones of Dudley and Llandilo; and finally, ancient Plutonic operations accompanied by elevations and alterations of the strata. We may now, upon sufficient data, affirm that the Welsh and Cumbrian series of slates presents a nearly complete record of all the principal deposits, with their characteristic organic remains from the gneiss and mica schist, upwards to the carboniferous system; and thus to show a continuity of marine operations in a part of the geological scale of periods where, in the time of Smith, was an utter blank.

In Wales, and on its eastern border, according to the now nearly united testimony of Sedgwick, Murchison, and De la Beche, (comprising, under this last honoured name, Ramsay, Selwyn, and the staff of the geological survey,) we have the following clear general section:—

* Some rare examples, probably in the upper part of this great group, of black slate with fucoids and graptolites.

Collective Titles.			Formations.		Name.	Prevalent Mineral Type.
LOWER PALÆOZOIC.	SILURIAN.	Upper	Ludlow..........	Fossils abundant.	Tilestone...........................	Arenaceous.
					Upper Ludlow......................	Argillo-arenaceous.
					Aymestry limestone...............	Calcareous.
					Lower Ludlow......................	Argillaceous.
			Wenlock.........	Fossils abundant.	Wenlock limestone................	Calcareous.
					Wenlock shale.....................	Argillaceous.
					Woolhope limestone..............	Calcareous.
		(Transition Group)....			Mayhill, or Upper Caradoc... Sandstone, &c.	Arenaceous.
		Lower	Bala or Llandilo.	Fossils abundant.	*Caradoc sandstone, &c............	Variable.
					*Bala limestone, &c. ——— slate flags....................	Variable.
	CAMBRIAN.		Festiniog or Lingula........	Fossils few.	Arenig slate and porphyry.........	Argillaceous, &c.
					Tremadoc slate......................	Argillaceous, &c.
					Lingula flags........................	Argillaceous, &c.
			Bangor or Longmynd....	No fossils known.	Harlech grits........................	Arenaceous.
					Llanberris slates and grits.........	Argillo-arenaceous.
					Longmynd slates....................	Argillo-arenaceous.

The metamorphic schists and quartzites of Anglesea belong mostly to the age of this bottom group. No organic remains known.

* In the Snowdonian districts these are not separable; generally they grow less and less distinct as we proceed westward and northward; sometimes one, sometimes the other type diminishing nearly to vanish. They appear to constitute one great variable group, whose palæontological value is about equal to that of the groups above. The distinction between the Mayhill and true Caradoc sandstone is still worthy of further scrutiny.

Bohemia.—Under the lowest zone of primary strata yielding fossils, are thick masses of earlier sediments, conglomeritic, arenaceous, and argillaceous—comparable to the "bottom zone" of North Wales—like that more or less slaty, and banded with trap rocks. These rest upon gneiss and granite.

The lowest fossiliferous zone is called by M. Barrande, the zealous and persevering explorer of the Bohemian Basin, the 'primordial'; it is an argillaceous series, comparable to the Festiniog or Lingula

zone of North Wales, and contains paradoxides, agnostas, &c. Igneous eruptions followed.

The zone which follows is composed of conglomerates, sandstones, and schists, contains trinuclei, ogygiæ, illænidæ ; it is the typical zone of the lower silurians of Murchison, including some black shales, but without the calcareous elements of Bala and Llandilo. The fossils in these shales are partly upper silurian, and are regarded as early colonies from some other region, in which those zones prevailed. Black schists with graptolites succeed, enclosing interposed bands of greenstone and trap. (Transition group.)

Next follow upper silurian grey argillaceous limestones, with carditæ, phragmocerata, orthocerata, pentamerus knightii, rhynconella navicula, and many other Wenlock or Ludlow species. This stage contains no less than seventy-eight species—the genera being mostly Wenlockian and Ludlovian. Two other bands of limestone ranging in great conformity succeed, and contain the same and analogous fossils. Grey shales form the highest observable silurian rock. The uppermost of the three limestones contains calymene, but also exhibits some Devonian affinities, by its included genus of goniatites, and some brachiopoda, which specifically are the same as Devonian forms. *Remains of fishes* lie rarely in the uppermost grey shale.*

On attentively considering the three complete sections now given of Cumbria, Wales, and Bohemia,—complete because they begin above hypozoic and end below Devonian strata,—and giving full weight to mineral as well as organic associations, the reader cannot fail to be struck with the essential accordance between them all. We have always two great zones, which may be thus defined.

Upper Zone—Contains limestones, and very numerous forms of invertebral marine life, trilobites, orthocerata, phragmocerata, crinoidea, cystidea, zoantharia, &c.

Divisible into two parts, this is the original *Silurian system* of Murchison. The two parts connected by a transition band (upper caradoc).

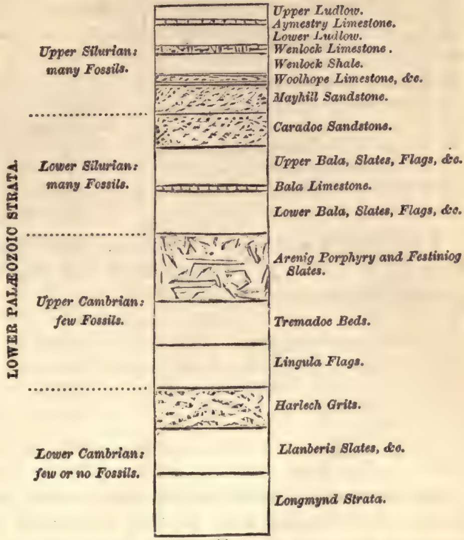
Lower Zone, without limestones, contains few forms of life, especially lingulæ, paradoxides, conocephalus, of species perhaps entirely, and genera mostly distinct from those above.

This zone divisable into two parts; the upper having in certain parts a poor fauna; the lower *not yet* found to yield any forms of animal life. The upper part is the primordial zone of M. Barrande, the lower part is the bottom zone of the government survey. Together they constitute what *was formerly understood* or supposed to be the subject of Sedgwick's special inquiry in Wales, and called *the Cambrian system*.

Finally, if we regard only the organic associations, the whole is but a great system of life, varying with time and local conditions, growing, expanding, and again contracting, to give place, at least

* This abstract is taken from 'Siluria,' Sir R. Murchison's latest view of the system of strata with which his name is indissolubly linked. P. 340, *et seq.*

partially, to a newer series. The following diagram, fig. 22 will be useful for reference.



22

North America, and especially the shores of Lake Superior, Canada, and the State of New York, affords another complete section of the lower palæozoic strata. To Mr. James Hall.* and Dr. Dale Owen† we are indebted for large and valuable illustrations of this fine series, which, being richly calcareous, offers points of interesting comparison with the more varied sections of Europe. This series is one deposited in comparative tranquillity, so that the whole series is generally conformable, and the conformity extends to the base of the carboniferous deposits.

The following is Mr. Hall's series. The separate reference to European types is founded on specimens and the views of Lyell, Sharpe, De Verneuil, and Murchison:—

Mr. Hall's Classification.		Reference to European types.
28. Chemung group	Erie Division.	18 to 28 Devonian, with fishes, spirifera, productæ.
27. Portage group		
26. Genessee slate		
25. Tully limestone		
24. Hamilton group		
23. Marcellus shale		
22. Corniferous limestone	Helderberg Division.	
21. Onondaga limestone		
20. Schoharie grit		
19. Cauda Galli grit		
18. Oriskany sandstone		
17. Upper Pentamerus limestone		12 to 17, Ludlow.
16. Encrinal limestone		
15. Delthyris shaly limestone		
14. Pentamerus limestone		
13. Water lime group		
12. Onondaga salt group		

* Geol. Survey of New York, ch. 3, 4. † Geol. Survey of Wisconsin, Iowa, and Minnesata.

Mr. Hall's Classification.		Reference to European types.
11. Niagara group	Ontario Division.	11. Wenlock limestone
10. Clinton group		
9. Medina sandstone		
8. Oneida conglomerate	Champlain Division.	7, 8, 9, Transition beds, P.
7. Grey sandstone		
6. Hudson River group		
5. Utica slate		
4. Trenton limestone		4, Llandilo limestone.
3. Black River limestone		
2. Calciferous sandstone		1, Lingula beds.
1. Potsdam sandstone		

Scandinavia and Russia combined give another complete, though thin (only 1,000 feet) section of the lower palæozoic series.* In general terms we may write it thus :—

Calcareous flagstones	Ludlow.
Coralline limestone and shale	Wenlock.
Pentameral limestone	
Black graptolite schists	
Orthoceratite limestone	Llandilo.
Alum slates with Olenus and Agnostus	Lingula zone.

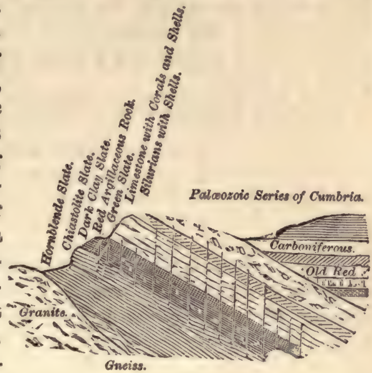
Inversely Proportional to the Gneiss and Mica Schist.—It may be frequently observed that two of the great groups of rocks which compose the primary strata are inversely proportional to each other. Countries which abound with gneiss and mica schist are indeed seldom quite devoid of clay slate, and the associated fossiliferous rocks, but they also seldom contain it in great quantity. On the contrary, where clay slate is extremely abundant, gneiss and mica slate are less extensively developed. This is at least very much the case in the primary mountains which surround and diversify the basins of Europe.

In Scotland the Grampian ranges, and, in fact, all the northern primary strata of that kingdom, are principally composed of mica schist and gneiss, while clay slates prevail almost exclusively in the southern chain of the Lammermuir and Galloway ranges, granite appearing in both districts. As before observed, the principal mica slate system in Ireland is distinct from the principal clay slate tract. The Cumbrian granitic rocks are surrounded by clay slates in great plenty and variety, but there is little gneiss or mica slate. The same is observed in the large primary tracts of Wales, Devon, and Cornwall, and it is a characteristic feature in the geology of the Harz. The hypozoic strata of Scandinavia predominate vastly in comparison of the diminished slates and lower palæozoics.

* From Murchison's Russia in Europe, vol. i., p. 10; and Siluria, p. 318, *et seq.*

Range of the Lower Palæozoic Strata.

Cumbrian Slate District.—The granite of Skiddaw is covered by gneiss and hornblende slates. The latter rock gradually changes to the chiastolite slate and other argillaceous slate of Skiddaw, and is no doubt a metamorphic variety of it. The argillaceous slates here commencing belong by all their mineral and structural analogies to the lower palæozoic strata, and form a series of three members, distinguished by their mineralogical characters, and a constant order of succession. See fig. 23.



23

Dark Lowest Slates.—The lowest slate rocks of the system range to the south-west from Skiddaw and Saddleback by Grisdale Pike to Dent Hill, filling the valleys of Derwentwater and Crummock water. South-west of Buttermere, they are concealed by the elevated ranges of High Steel and Red Pike, but reappear in the lower parts of Ennerdale, and abut against the limestone border near Egremont.

24 Mountains of Skiddaw slate.

The slate of this district is generally of a dark bluish or blackish colour, of very uniform texture, soft, fine-grained, and very fissile, and has been employed in the vicinity of Keswick and Hesket Newmarket for roofing houses; but for this use it is not very suitable, for it easily perishes in the atmosphere. In consequence of its want of durability, the mountains of this slate have smoother contours, more uniform slopes, and a more verdant surface than those of the following series.

Sedgwick remarks four varieties in the following downward order:

d. Black slate with fucoids and graptolites.
c. Grits, fine-grained.
b. Black slate.
a. Chiastolite slate.

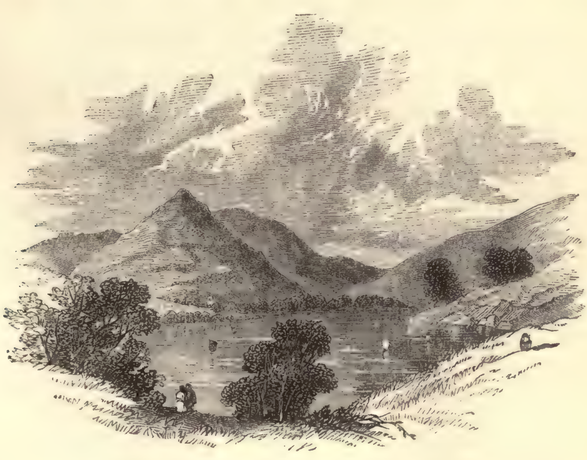
In one point on the south-western edge of Derwentwater, we have observed an undulated variety of this slate of paler colour and more shining surfaces, indicating an approach to the nature of chlorite slate. Chiastolite is embedded in the lower part of the rock in Skiddaw and Bowscale Fell. Where this slate shows itself by the sides of the lakes, its laminæ appear to be generally vertical, and often flexuous. Veins of quartz are frequently seen penetrating and interlaminating its masses. In several places they yield abundance of lead ore; and in the district called Newlands, abundance of carbonate of copper, and some cobalt. Mr. Otley states that the lead veins run north and south, and those of copper east and west. Steatite is found in Borrowdale, and mixed with the slate in Martindale. Two salt springs have been detected in it near the upper end of Derwentwater.

Green Middle Slates.—These rocks, sloping to the south-east and north-west from Skiddaw and Saddleback, are covered by the middle system of slates. These are best developed on the south-eastern slopes, and occupy a long range of mountains parallel to the Skiddaw slates, in those highly picturesque and romantic valleys wherein the lakes of Ulswater, Haweswater, Thirlmere, and Wastwater, spread their beautiful waters.

The lowest rock belonging to this system is a red, argillaceous, fissile stratum, abundant in the eastern shores of Derwentwater, especially about Barrow and in St. John's Vale, in both localities resting upon the Skiddaw slate.

Red Rock.—It is a very singular rock, characterized universally by its mottled colours, and apparently heterogeneous composition. Its first aspect reminds us of an old red sandstone conglomerate, but on closer inspection, the seeming certainty of its brecciated character vanishes; the seeming fragments of which it is composed appear to be scarcely more than colour spots, and we leave the rock very unde-

cided as to its origin. In some cases, however, it must be owned, the appearances of aggregation are very difficult to withstand. It is distinctly stratified, with dip to the south-east, and is of considerable thickness. Its pervading tints vary from bright red to purple, and in proceeding up Borrowdale, rocks succeed in the same geological position, at first blue, and afterwards greenish, while the seeming conglomerate aspect becomes less distinct, the spotting is smaller, the hardness greater, the rock splits vertically, and becomes, in fact, a coarse green slate. Amidst the numerous varieties which succeed, we perceive about the Bowder stone some remarkable laminated beds, with talcose surfaces, and variegated with nodular concretions of calcareous spar, green earth, and differently coloured quartz or calcedony, having altogether very much the aspect of amygdaloid. This peculiar metamorphosed slate, which seems to indicate the united agency of water and great heat, dips in the same direction as the red rock of Barrow, and thus helps to prove that in this tract the vertical cleavage of slate is transverse to the lines of deposition. It appears to harden and change to a truly trappean character in Wallow Crag. There are, perhaps, repetitions of this remarkable rock in other parts of the slate system, since it occurs at the upper end of Ulswater, in Helm Crag, Loughrigg, and other points about Grasmere and Elter Water, in Ulpha, and other places. But it is possible that these may be the same beds; a conjecture supported by the fact, that red rocks, like those of Barrow, lie beneath them at Grasmere. And, indeed, in Helvellyn and other mountains, we



25 Helm Crag and Grasmere.

see the coarse slate rock vary through all appearances from amygdaloidal slate to fragmentary greywacke, and this again assuming more regularity, resemble clay porphyry, and finally become real porphyry, with subnodular or truly crystalline felspar. On the other hand, we see the coarse rocks of Borrowdale and Patterdale lose their spotted aspect, become more uniformly green, more regularly fissile, and change to the fine-grained green slates of Langdale and Coniston Fells, or the pale grey rocks around Grasmere, or the 'rain spot' slate of White Moss.

As yet no other traces of organic remains have been noticed except some oval bodies, or rather cavities, perhaps marks of petraiæ, which are extended along the planes of cleavage in the grey strata of the Old Man.

The minerals which this district yields are rather numerous than valuable. The veins are generally quartzose. A great variety of lead spars, sulphuret and carbonate of copper, with galena, pitchy iron ore, wolfram, &c. are found in Caldbeck Fells, among the slaty and syenitic rocks. Galena has been worked in Grisdale (Ulswater), copper ores at Coniston and in the lower beds in Newlands, plumbago in Borrowdale, micaceous iron ore in Eskdale, &c.

In consequence of its superior hardness, and its frequent association with igneous products, the green slate mountains assume bolder forms, present more lofty and rugged peaks, and more inaccessible precipices than the softer slates of Skiddaw. For the same reason,

26 Langdale Pikes.

the streams, instead of furrowing the smooth slopes in straight

courses, are twisted about among the unyielding rocks, and broken into admirable cascades.

Dark Limestone.—The region of green slate is rather indefinite toward the south-east, where it is overlaid by the uppermost series of slates. Perhaps it may be best to adopt as the conterminous line, the narrow course of dark calcareous slate, formerly called 'transition limestone,' which passes from Long Sleddale by Low Wood Inn and Windermere Head to Coniston Water Head and Broughton Mills. This rock contains organic remains, as petraiæ, heliolites, orthis, orbicula; but generally in so imperfect a state of conservation, owing to the prevalence of slaty cleavage in the rocks, that their specific characters are obscure. The calcareous layers alternate with layers of slate of the same colour, and are with difficulty distinguished from them. Their dip is usually very rapid to the south.

Upper Slates.—Above this regular band of limestone lies a thick series of rocks, containing several varieties, all capable of being ranked as sandstones and slates. The lower rocks, very dark in colour, are frequently quarried for slate (Broughton, Ulverstone, &c.), occasionally for flagstones and tombstones (near Hawkestone, Crooks of Lune, &c.), which are sometimes parallel to the stratification. (Otley, *Guide to the Lakes.*) In the long aberrant range of slate rocks beneath Ingleborough and Penyghent, (*Geol. Trans.*) dark slate of similar aspect reappears in Clapham Dale and abounds in Ribblesdale, and furnishes enormous tables of slate with nodules sometimes formed round lituites, orthoceratites, &c. in the nearly vertical partings or cleavage. At Ingleton the greenish slate seems rather referable to the middle slate system.

Above the dark uniform slates previously described lies a system of more micaceous and more granular rocks, which extend to the south-eastern border of the primary district. They are of two kinds: 1, fissile, with micaceous partings parallel to the stratification, sometimes reddish, and appearing to resemble certain laminated red sandstones; 2, granular, not fissile, with disseminated mica. These varieties may be observed frequently alternating in the country north of Kendal, and about Kirkby Lonsdale, and present the most striking analogies to arenaceous freestone and micaceous flagstone. In the upper part of this system (near Kendal and near Kirkby Lonsdale) lie layers of shells, or rather casts and impressions of shells of the following genera: terebratula, orthis, orbicula, pterinea, avicula, orthonota, turritella, orthoceras. (*Geol. Trans.*)

Cleavage of Slate.—A very remarkable feature in the region of this upper slate series, is derived from the uncommonly crystalline aspect of the rock on a large scale. The numerous joints intersecting one another at acute angles, and ranging with admirable precision for a hundred yards or more, divide the faces of the hills into long ridges

of smooth, rhomboidal rocks, alternating with parallel heathy or grassy hollows. This is probably the reason of the peculiarly rough and knotted appearance of many hills of this tract. It is difficult to resist the belief that this is owing to a real crystallization, and that slate is a crystalline rock with definite angles and regular cleavage. But on pursuing the inquiry it will be found that the parallelism of external joints and internal cleavage is a phenomenon of a different kind from geometrical crystallization, not produced in consequence of an original equilibrium amongst the particles, but from symmetrical consolidation of the mass, nearly as the cuboidal blocks of oolite, the rhombs of shale, and prisms of basalt have been formed.

Among the less common appearances of cleavage is that represented in fig. 15, p. 44, where different layers (strata) of slate are cleavable at different angles of incidence.

27 Honiston Crag and Buttermere.

Rocks of igneous origin are plentiful in the Lake district. In the region of Skiddaw slate, we have the gray granite, already mentioned, at Syningill, between Skiddaw and Saddleback, and in the valley of the Caldew. It sends veins through the metamorphic slates which rest upon it, and being on the axis of the great movement of the district, must be supposed to have been protruded by a convulsion perhaps of later date than any of these rocks. The syenite, sometimes hypersthenic, generally rich in titaniferous oxide of iron, of

Carrock Fell, is different from any other rock in the district. I am not aware that it sends out veins, and as it is not on the general axis of movement, probably it is to be counted among the older igneous masses. The gray granite of Eskdale and Devock Lake has been carefully traced by Sedgwick, and shown to be a large mass, ramifying into Skiddaw slate, near Bootle, and green slate near Wastdale Head and Eskdale Head. The ramifications are felspathic. The fine red syenite of Red Pike and Scale Force has a considerable range on the north side of Ennerdale Water, penetrating Skiddaw slate in veins, and uplifting it in masses; the green slates and porphyries are also penetrated by its veins.

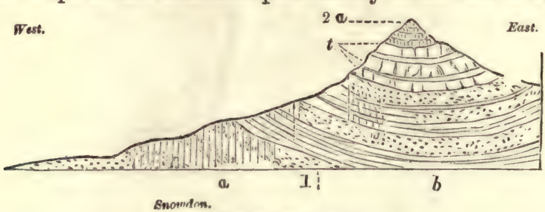
28 Scale Force.

The red granite of Shapfells is distinct from all the foregoing by its large included crystals of red felspar. It is of comparatively late date, cutting off and penetrating or disturbing the strata of the Con-

iston, and even higher groups. The red porphyry mass with garnets in St. John's Vale, lies on the lower part of the green slates. Dykes of porphyry and felspar, red, greenish, and gray, divide the green slates in several places; and though they cannot be often *traced* to subjacent granite or syenitic masses, we have little doubt that they really are in most cases ramifications from such rocks. Kirkfell, Wastdale Head, Armboth Fell, above Thirlmere, the channel of the Duddon, near Seathwaite, the vicinity of the granite of Shapfells, and the foot of Coniston Lake, are localities specially cited by Sedgwick.* Greenstone bands are frequent, and porphyritic interposed beds interlaminate the green slate series.

Range of Lower Palæozoics in Wales.

The bottom group of the lower palæozoic series (fig. 29) is seen in four districts of Wales, viz., gray and purple gritstones, bordered by felspathic traps in the anticlinal promontory of St. David's; a large



29 Section of Snowdon.

1 *a* Bottom beds of Cambrian group. *b* Lingula beds of Cambrian group: 2 *a* Bala beds or Lower Silurian; *t* interposed trap. Vertical lines mark cleavage:

mass of hard gray and purplish grits in a broad anticlinal about Harlech; an elongated patch denuded on the western sides of Snowdonia, and crossing the valleys of Llanberris and Nant Frangon, (this shows thick slates and grits under the Harlech grits;) and a large mass of vertical gray and purplish slaty, gritty, and pebbly rocks near Church Stretton, called the Longmynd. Trap rocks accompany here the unfossiliferous slates, and diversify a series, supposed to be 26,000 feet thick!

The Festiniog group (*b* fig. 29), in which are the earliest traces of life yet known, is not so different by any mineral or structural character from the earlier group, as by this means to account for its different relation to life. It is of a later age, truly falls within the life period for this part of the globe, and that is perhaps the only reason we can give at present. The typical localities of this series form a semicircle

* Letters on the Geology of the Lakes.

round the Harlech anticlinal, from near Barmouth and Dolgelly to Festiniog and Tremadoc; other ramifications run both on the south-east and north-west sides of Snowdonia, the upper portion appearing in the Arenig. About the Longmynd these strata show no lingulæ, but are represented by the grits and flags of the Stiperstones.

The lower part of the Bala group (2 *a* fig. 29), as the name implies, is very fully seen, with calcareous members, about the great Lake of North Wales, and much disturbed in position in the Berwyn mountains, and in the country south of Llangollen. About Llanidloes, Rhayader, and Builth, it appears without limestone; in the latter tract much mixed with bedded and some intrusive trap, but recovers its partially calcareous character at Llangaddoc, Llandilo, and Golden Grove, St. Clairs, Mydrim, and Lampeter Velfrey. Beds of this age lie upon the Stiperstone rocks, and are penetrated by trap at Corndon. Perhaps the lowest shales of the Malvern district with oleni, agnostus, &c. may be referred to this group.

On the top of Snowdon we have Bala beds with fossils. The true Caradoc or upper part of the Bala group is combined in the Ordnance

30 Snowdon, from the East.

survey sheets of Wales, with the Mayhill or Upper Caradoc,* which contains many Wenlock fossils. Thus combined, Caradoc beds range almost continuously from Conway to Llanwrst and Corwen, west of Llanfair and Newtown, to the borders of Radnor Forest. From this

* This name was suggested by myself, from finding the upper part of the Caradoc of Malvern very distinguishable from the lower. (1842.) The term Mayhill sandstone was proposed by Sedgwick, and includes a thicker slice from the old Caradoc.

point westward they are not represented on the map, though here and there, pretty frequently, sandstones and conglomerates, partially fossiliferous, interlaminate the shales and slates of Rhayader, and Llandovery, as far as Llandilo. The great ridge of Caer Caradoc running by Church Stretton to the Wrekin is a fine type of these rocks. The upper Caradoc makes most figure about the Malvern hills; it rests on the thick partially conglomeritic fossiliferous grits, which compose the summit of Mayhill, and exchanges beds, or admits of alternation with the lower members of the Wenlock formation. Excepting the ridge of Caer Caradoc and the vicinity of Coalbrookdale, I am not aware of remarkable trap eruptions which penetrate the Caradoc beds. In the Malvern district the lower portions rest upon trap bosses of earlier date. The sandstone of the Lickey is of this series.

The Wenlock group of shales and shaly sandstone, without developed limestones, ranges from the vicinity of Conway and Llanwrst, to Corwen and Llangollen. Interrupted by the over-extended carboniferous and permian strata, it reappears in the Long Mountain, west of Shrewsbury, and occupies large space about Llanfair, Montgomery, and Newtown; surrounds the anticlinal district of Builth, and runs in a narrow course on the south-east of Llandovery, Llangadoc, and Llandilo. At Pwll Calc, near Llangadoc, it yields limestone. In another remarkable range, from Radnor, by Presteign, Ludlow, and Wenlock Edge, to the Severn banks, the Wenlock formation is complete, the limestone prominent and characteristic. So is it in the Malvern range, west of the syenite, at Woolhope, Mayhill, Tortworth, and Usk, and Marloes Bay.

The limestone of the Wren's Nest, Dudley, and of Walsall, belongs to this group. The uppermost silurian group, that of Ludlow, is scarcely distinct in any district where the Wenlock limestone is absent; except by its fossils, it would perhaps hardly be distinguishable, and many of them are too local to be thus employed. Distinct in place and character, and exhibiting Aymestry limestone, it ranges parallel to the Wenlock group from the Severn at Coalbrookdale to Ludlow and Aymestry, and spreads over a large space about Clun, Knighton, and Radnor Forest. It takes a wide sweep round the Builth anticlinal, and is traceable in a band growing narrower and narrower, by the north-west part of Mynydd Eppynt, and north of the ridge which forms the southern horizon of Llandovery, Llandilo, St. Clair, and Narberth. It is last seen at Freshwater east and Freshwater west, and in Marloes Bay, beyond Milford Haven. On the south-eastern borders of Wales, regarded as a natural district, we have these richly fossiliferous rocks conspicuous in the Abberley, Malvern, Woolhope, Mayhill, Tortworth, and Usk districts, and they are traceable at Sedgeley, near Dudley, and at Walsall.

Cornwall.—The general impression concerning the schistose rocks of Cornwall is that their mineral composition is a mixture of quartz, felspar, and mica; and so, probably, is that of most clays and shales.

The extensive deposit of serpentine of the Lizard is seen in several places to rest upon and alternate with greenstone and porphyry, in others to rest upon green talc or clay slate. At Coverack are rocks of various texture, in some measure intermediate between serpentine and diallage rock, which suggest important reflections on the relation of this beautiful rock; and in the same place, the greenstone abounds with diallage, and contains likewise titaniferous oxide of iron. Veins of steatite divide the serpentine, and are thought by Sir H. Davy to be derived from decomposed felspar. Dykes of syenite and saussuritic diallage rock pass through the serpentine.

The Killas is a true slate, but its geological date is often later than the silurian era: the granite of the Ocrynean chain bursting through and affecting strata of various ages. In contrast with granite it is much interlaminated with porphyritic masses, quartz veins, &c.

Scotland.—Clay slates resting on mica schist and chloritic schist, perhaps cœval with the Bottom rocks of Wales, occupy a narrow range on the south-east front of the Grampians, and cross Loch Lomond from north-east to south-west, run through Bute, and wrap round the granite of the north-east part of Arran. Another less continuous range appears in the south-westward prolongation of the remarkable valley of Loch Ness. Balachulish and Dunolly, near Oban, show these dark pyritous slates and quartzites well. They occur by Loch Eil, in Lismore, in Jura, and Isla. No fossils accompany these rocks.

A much larger tract in the southern part of Scotland, ranging in a parallel course to the Grampians, from the Mull of Galloway to St. Abb's Head, has yielded to Sir J. Hall, Nicol, and Harkness, Milne, Murchison, and Sedgwick, a considerable number of silurian fossils, and a tolerable basis of classification begins to appear among the greatly disturbed strata of that large region. The confused axis of the country seems, by the inquiry of Nicol, to be traceable through Roxburghshire, and to contain purplish, often conglomeritic members without fossils. The schists which overlie are partly anthracitic and partly aluminiferous; still no fossils till we ascend toward the top of this thick group, and then graptolites and annelida appear, succeeded by trilobites. Felspathic porphyries are interlaminated. Then comes the only limestone—that of Wrae in Peeblesshire, with asaphus tyrannus, Illænus Bowmanni, orthis calligramma, orthoceras. If these be taken as evidence of Llandilo, or Caradoc bands, we find still some higher members.

What appeared the most probable evidence of upper silurians

occurred to Murchison* in the coast section south of Girvan, and in the vicinity of Kirkcudbright; but the whole of the country requires more work, though the main features of the section are established. The frequency of contortions, and the great effect of igneous agency in Criffel (syenite), and the large granitic tract of New Galloway, impart much interest to what would otherwise be a dull region of shales, sandstones, and conglomerates. It is limestone which enlivens siluria.

Ireland.—Mr. Weaver describes the slate which borders the granitic tracts south of Dublin, as alternating with greenstone and greenstone porphyry, and enclosing clay slate conglomerates.

In Windmill Hill, Mr. Weaver describes several alternations of a granular felspathic rock with the clay slate. And in the mountain of Croghan Kinshela, in the space of 630 fathoms, are eight principal beds of alternating granite and clay slate, besides several of granite and clay slate mixed, and four of clay slate and greenstone.

Clay slate and quartz rock are likewise seen in frequent alternation on the eastern coast of Ireland, and thus remind us of the similar rocks in Anglesea.

The Siluro-Cambrian series of Ireland is not yet certainly known to be anywhere complete in one district. The lingula beds are absent. The bottom beds yield one fossil genus. Unconformity is observed between the lower silurians and the bottom zone.

Upper Silurian Zone.—In the cliffs of Ferriter's Cove (seen 1843). Possibly also in Connemara.†

Lower Silurian Zone.—Well seen in the picturesque narrow Bay of Killery; at Pomeroy in Tyrone;‡ in the chain of Kildare, and in the sea coast near Tramore.

Bottom Zone.—In Wicklow and Wexford, black slates; and at Brayhead, laminated purple schist and sandstone, with one zoophyte, Oldhamia, which I gathered there in great abundance with Mr. Oldham in 1844. Some of the purple and grey grits and quartzose conglomerates in the county of Cavan appear to be of the parallel of the Longmynd. The hard rocks of Lisbellaw, full of quartz pebbles, are probably of great antiquity. Near them are lower Silurian fossils. The Lisbellaw pebbles are such as might be derived from the veins in mica schist, chlorite schist, &c. §

The Isle of Man contains a large breadth of old slaty rocks, divided by granitic and porphyritic dykes and partly metamorphic.‖

Charnwood Tract.—The green slates, perhaps, of the middle Cumberland group are completely traversed by cleavage, and yield no fossils, unless a drawing which I have seen represent an annaliol.

At Nuneaton, Silurian strata appear.¶

* Geol. Journal, vii., 137. † Portlock's Report on Geol. of Londonderry, Tyrone, &c. ‡ Murchison's Siluria, p. 116. § Jukes' Geology.
‖ Henslow in Geol. Trans., vol. v. Cumming's Isle of Man. ¶ Silurian System.

Disturbances of the Lower Palæozoic Strata.

During their Accumulation.—Though during the accumulation of these rocks beneath the waters of the sea, considerable tranquillity and a repetition of similar circumstances prevailed, as may be inferred from the correspondence of the stratification, the comparative infrequency of conglomerates, and the general agreement of the organic remains at different points over immense surfaces, yet some remarkable exceptions occur, enough to show that the subterranean forces to which our continents owe their present forms and elevations, were not wholly inactive. In the Cumbrian mountains, especially, we may clearly perceive the effects of some considerable local disturbance in the conglomerate rocks of St. John's Vale, Barrow, and Grasmere; and the singular admixture and blending of porphyries, amygdaloids, and greenstones, with the ordinary argillaceous slates, proves evidently a great and continued development of igneous agency *during* the deposition of the middle slate rocks of the lakes. Similar effects appear to have happened extensively about Snowdon and Cader Idris, about Bala Lake, and on the north front of the Berwyns; in the Longmynd near Shrewsbury; in the Caradoc; in the anticlinal tracts of Buillt, and in the axis of Cardiganshire, about Precelli mountain and St. David's. These indications of disturbing heat-action are repeated in several bands of the Cambrian and lower Silurian rocks; they scarcely appear in the upper Silurian, and indeed are for the most part anterior to the Caradoc sandstone.

Other evidence of these disturbances occurs in the observed positions of the strata. In Ireland, we learn from the geological survey, through Mr. Jukes, that the Longmynd rocks were displaced and upturned in Wicklow previous to the formation of the black slates, which, without lingulæ, overlie them *unconformably*. This appears the oldest case of disturbance yet clearly traced.

The next in point of time seems to have occurred after the deposition of the lower Caradoc, for on this rock rests with some unconformity the upper Caradoc in the Onny River, and for a considerable range about the trap districts of Corndon, it rests unconformably on Llandilo schists. The upper Silurian rests unconformably on the upturned edges of the Llandilo series, near Builth. The Llandilo rocks are here interlaminated with trap.

After the Deposit of the Silurian Strata.—But immediately after the completion of the silurian deposit, a much more general and more violent succession of dislocations happened. At this period many of the primary ranges of the British Islands received their most remarkable features; and it is deserving of notice that some of the most important of the lines of elevation and depression then produced by sub-

terranean expansion,—for instance, the Grampians, the valley of the Caledonian Canal, the Lammermuir hills, and the prolongation of these ranges in Ireland, the Cumbrian chain, and the hills of the Isle of Man,—run in nearly the same direction from north-east to south-west. Now all these chains were thrown up, though not exactly to their present height and aspect, after the termination of the silurian ages, and before the deposition of the old red began there. The old red on the borders of those mountains is usually conglomeritic, a monument of the aqueous violence set up by dislocation of the old land and sea. We seem, therefore, to have in this a striking example in favour of Elie de Beaumont's hypothesis of the accordance between the direction of the axis of a mountain group and the date of its elevation. But the mountain systems of Wales are generally bordered by *conformable* old red, except along the north-eastern limit from Conway to Shrewsbury, and about Haverford-west; phenomena which indicate a post-silurian disturbance of the central axis of the lower palæozoics of Wales, not reaching in breadth far to the south-east, for there the old red is very conformable to the silurians.

Influence on the Mean Direction of Strata.—In consequence of these elevations, the older strata of Scotland, Cumberland, Man, Donegal, the Mourne, Wicklow, North Wales (perhaps we may add Cornwall, the silurian series there being very limited), thrown up towards central ridges, exhibit, amidst many irregularities, prevailing dips towards the south-east and north-west, and have thus considerably influenced the mean bearing of all the subsequent deposits of British strata in which a very general tendency to the north-eastern and south-western directions has been for a long time observed.

Plutonic rocks are often visible along the axis of these ancient elevations. The Cumbrian chain encloses a line of nuclei of granite, syenite, and hypersthene rocks, besides various porphyries and greenstones in dykes, and overlying plateaux, of which the age is less certainly indicated. These have evidently been injected in a melted state into fissures produced during the general movement of the stony masses; but there is proof derived from veins, and from the appearances at the points of their contact with other rocks, that the central granitic masses were uplifted in a melted state. In Cornwall, in the north of Ireland, and still more generally in Scotland, the granitic rocks were evidently in a state of fusion, since the deposit of the slates, and, accordingly, these latter rocks, and the various strata associated with them, are often penetrated by veins of granite, and materially altered at the surfaces of contact. Have the fissures occasioned by these intestine subterranean movements furnished the cavities which have since, by injection, sublimation, and segregation, been filled by various metallic and mineral substances?

Mineral Veins.—These *mineral veins* are, upon the whole, more nu-

merous in the primary strata than in any of the secondary rocks; and the generally admitted fact that they are not all of the same age in the same mining country, may lead us to suppose that their production was not confined even to one great epoch in geology, but was repeated at intervals during the whole period of the formation of the strata.

Organic Remains of the Lower Palæozoic Strata.

The strata which have now passed under review contain the oldest known forms of organized beings, the oldest remains of life; *probably* among them are the traces of the earliest fauna and flora we shall ever discover; *possibly* they are the reliquiæ of the earliest which ever existed on this globe. What a thought is this! How does it stamp with a high and solemn character the labours of the palæontologist! With what cautious preparation should we approach a subject so difficult and mysterious.

The earliest traces of life yet marked on the scale of geological time occur in the group of the Cambrian strata, some thousands of yards below the calcareous bands of Bala and Llandilo, to which in 1839 the lower limit of the Silurian system, marked by numerous fossils, had been extended by Murchison. This earliest known flora and fauna consists of the following groups (*in the British strata*):—

Of land animals or plants—None.
Of fresh water animals or plants—None.

Of marine plants the following:—

Note.—The genera marked * are not known to occur in any higher group of the strata; so that among the 12 genera and 15 or 19 species admitted as British in this zone, we have six genera, and probably every one of the species *peculiar to it;* a truly primordial group of life, composed of peculiar Algæ, Bryozoa, Brachiopoda, and Crustacea of two orders only. Not one lamelliferous, gasteropodous, or cephalopodous mollusk; no fish or reptile! Was this the whole or even a large part of the then world of life?

Chondrites acutangulus	M'Coy	North Wales, Skiddaw.
* Cruziana semiplicata	Salter	North Wales.
——— N.S.	Do.	Do.
* Palæochorda major	M'Coy	Kirkfell.
——— minor	M'Coy	Blakefell, under Crag.

Fucoid plants occur in this primordial zone in Bohemia, Norway, Sweden, and North America (perhaps the lowest sandstone of Malvern with fucoids may belong to it; but Sedgwick thinks it to be of later date). Of marine animals the following:—

Bryozoa	Fenestella	Salter	North Wales.
———	* Oldhamia antiqua	Forbes	Brayhead, Ireland.
	second species	———	Do.
Brachiopoda	Lingula Davisii	M'Coy	North Wales.
Orthis	———	Salter	Do.

Crustacea—

Phyllopoda ...	* Hymenocaris vermicauda...	Salter.........	North Wales.
Trilobitida......	Olenus micrurus	Salter.........	North Wales.
	* Paradoxides Forchhammeri	Angelin	North Wales.
	Agnostus pisiformis	——	North Wales.
	* Conocephalus	Salter.........	North Wales.

All the genera of trilobites occur again in the primordial zone of Scandinavia and Bohemia. (At Malvern, in black shales much resembling the alum slates of Norway occur—

Olenus humilis Phil.
bisulcatus Phil.
scarabæodes ? Wahl.
Agnostus pisiformis.

Sedgwick thinks these shales belong to a higher part of the series).

We may now compare the three groups of Cambrian, Lower Silurian, and Upper Silurian strata, in respect of the *number of genera* admitted in each group, and in each of the great divisions of *animal life.* The genera are taken in conformity with Morris's Catalogue of British Fossils (1854), a work of great and permanent value:—

	Cambrian.	Common to C. and S.	L. Silurian.	Common to L. and U.	U. Silurian.
Amorphozoa,	...	...	2	1	2
Foraminifera,	...	...	...	...	1
Zoophyta,*	...	...	18	13	32
Echinodermata,	...	...	6	1	20
Annelida,	...	...	8 ?	2	5
Crustacea,	5	2	31	14	19
Bryozoa,	2	1	4	2	10
Brachiopoda,	2	2	13	11	16
Monomyaria,	...	...	5	3	3
Dimyaria,	...	...	10	9	16
Pteropoda,	...	...	4	3	3
Gasteropoda & Heteropoda,	...	...	16	10	13
Cephalopoda,	...	...	5	5	5
Fishes,	...	...	...	...	4
	9	5	122	74	149

The lists which follow comprise the names of genera (grouped in classes); the approximate number of species in each; the distribution of these species in the three great though unequal fossiliferous groups or stages on the scale of Lower Palæozoic life. The genera which occur in the lower stage are printed in small capitals; those which appear first in the middle stage are in Roman, and the Italic character is assigned to those which do not appear till the third stage. These distinctions will, no doubt, be somewhat altered by the progress of discovery. The *species* of plants are indicated:—

* Graptolithus latus, M'Coy, is quoted from Skiddaw, and supposed to be from the upper part of the Cambrian group. In no other case is any graptolite known below the Lower Silurian beds.

PLANTS.

ALGÆ—MARINE PLANTS.

			Lower Stage, (Cambrian.)	Middle Stage, (Lower Silurian.)	Upper Stage, (Upper Silurian.)
CHONDRITES	acutangulus,	M'Coy	Bangor, Skiddaw.		
	antiquus,	Brongn	......	......	U. Ludlow.
	informis,	M'Coy	......	Whitless (Cum.)	......
CRUZIANA	semiplicata,	Salter	Bangor	......	......
	new species,	Do.	Do.	......	......
Fucoides gracilis,		Hall	......	Malvern	......
PALÆOCHORDA, major,		M'Coy	Kirkfell	......	......
	minor,	M'Coy	Blakefell	......	......
Traces of land plants (*Lepidostrobūs*) at the top of the Ludlow, or base of the old red deposits,			......	......	Stoke Edith, Hagley, &c.

AMORPHOZOA.

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Acanthospongia?	1	...	1	...
Cliona,	2	...	1	1
Cnemidium?	1	...	...	1

FORAMINIFERA.

Endothyra,	1	...	...	1

ZOOPHYTA.

ZOANTHARIA of Edwards.

Acervularia,	1	...	...	1
Alveolites,	4	...	...	4
Arachnophyllum,	1	...	...	1
Aulacophyllum,	1	...	...	1
Aulopora,	3	...	...	3
Chætites,	4	...	1	3
Cladocora,	1	...	...	1
Clisiophyllum,	1	...	...	1
Cœnites,	5	...	...	5
Cyathaxonia,	1	...	...	1
Cyathophyllum,	5	...	1	4
Cystiphyllum,	4	...	...	4
Diphyphyllum,	1	...	...	1
Favosites,	7	...	3	6
Fistulipora,	1	...	...	1
Goniophyllum,	2	...	...	2
Halysites,	1	...	1	1
Heliolites,	10	...	6	8
Nebulipora,	4	...	3	1
Palæocyclus,	4	...	...	4
Petraia,	7	...	7	1
Pyritonema,	1	...	1	...
Protovirgularia,	1	...	1	...
Sarcinula,	1	...	1	1

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Stenopora,	1	...	1	1
Strephodes,	5	...	1	4
Stromatopora,	2	...	...	2
Strombodes,	2	...	...	2
Syringopora,	5	...	...	5
Thecia,	2	...	...	2
Zaphrentis,	2	...	...	2
ALCYONARIA.				
Didymograpsus,	3	...	3	...
Diplograpsus,	10	...	10	...
Gorgonia ?	4	...	3	1
Graptolithus,	12	...	11	2
Rastrites,	1	...	1	...
Retiolites,	1	...	1	1
HYDROIDIA.				
OLDHAMIA,	2	2	...	...

ECHINODERMATA.

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
CRINOIDEA.				
Actinocrinus,	4	...	...	4
Crotalocrinus,	1	...	...	1
Cyathocrinus,	3	...	...	3
Eucalyptocrinus,	3	...	...	3
Glyptocrinus,	1	...	1	...
Ichthyocrinus,	1	...	...	1
Marsupiocrinus,	1	...	...	1
Periechocrinus,	2	...	...	2
Sagenocrinus,	2	...	...	2
Taxocrinus,	2	...	...	2
Tetramerocrinus,	1	...	...	1
Trochocrinus,	1	...	1	...
Tetragonis,	1	...	...	7
CYSTIDOIDEA.				
Agelacrinites,	1	...	1	...
Apiocystites,	1	...	...	1
Caryocystites,	5	...	5	...
Echinoencrinus,	2	...	...	2
Echinosphærites,	4	...	...	4
Hemicosmites,	2	...	2	...
Prunocystites,	1	...	...	1
Pseudocrinites,	4	...	...	4
ASTROIDEA.				
Lepidaster,	1	...	...	1
Protaster,	1	...	...	1
Uraster,	4	...	1	3
ECHINOIDEA.				
Palæchinus,	1	...	...	1

ARTICULATA.

ANNELIDA.

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Aphrodita?	1	...	1	...
Cornulites,	1	...	...	1
Crossopodia,	2	...	2	...
Lumbricaria,	2	...	2	...
Myrianites,	1	...	1	...
Nemertites,	1	...	1	...
Nereites,	3	...	3	...
Serpulites,	4	...	...	4
Spirorbis,	1	...	...	1
Tentaculites,	3	...	2	2
Trachyderma,	3	...	1	2

CRUSTACEA.

ENTOMOSTRACA (TRILOBITIDÆ.)

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Acidaspis,	10	...	4	7
Æglina,	2	...	2	...
Agnostus,	4	1?	4	...
Amphion,	1	...	1	...
Ampyx,	5	...	4	1
Asaphus,	7	...	7	...
Bronteus,	2	...	1	1
Calymene,	6	...	5	2
Cheirurus,	4	...	4	1
CONOCEPHALUS,	1	1	.	..
Cybele,	2	...	2	...
Cyphaspis,	1	...	1	1
Cyphoniscus,	1	...	1	...
Deiphon,	1	...	...	1
Eccoptocheile,	1	...	1	...
Encrinurus,	4	...	3	2
Harpes,	2	...	2	...
Homalonotus,	5	...	3	2
Illænus,	8	...	7	1
Lichas,	9	...	7	2
Ogygia,	2	...	2	...
OLENUS,	4	1 or 4?	3?	...
PARADOXIDES,	1	1	...	...
Phacops,	15	...	15	3
Proëtus,	3	...	1	3
Remopleurides,	7	...	7	...
Sphærexochus,	1	...	1	1
Staurocephalus,	2	...	2	...
Stygina,	2	...	2	...
Tiresias,	1	...	1	...
Trinucleus,	5	...	5	...

(OTHER ENTOMOSTRACA.)

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Beyrichia,	3	...	2	1
Ceratiocaris,	3	...	...	3
Cythere,	1	...	1	...

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Dithyrocaris,	1	...	1	...
Eurypterus,	2	...	...	2
Hymenocaris,	1	1	...	...
Leptocheles,	2	...	...	2
Pterygotus,	1	...	...	1

BRYOZOA.

Cellepora,	1	...	...	1
Ceriopora,	5	...	...	5
Diastopora,	2	...	1	1
Discopora,	3	...	...	3
Escharina,	1	...	...	1
Fenestella,	6	1	...	6
Glauconone,	1	...	...	1
Heteropora,	1	...	...	1
Intricaria,	1	...	1	...
Oldhamia,	...	2	...	...
Polypora,	1	...	...	1
Ptilodictya,	8	...	6	2
Retepora,	1	...	1	...

BRACHIOPODA.

Athyris,	6	...	...	6
Atrypa,	9	...	1	8
Chonetes,	1	...	...	1
Crania,	3	...	1	2
Cyrtia,	1	...	...	1
Discina,	12	...	6	6
Leptæna,	42	...	28	17
Lingula,	16	1	8	6
Obolus,	2	...	...	2
Orthis,	45	1	39	11
Orthisina,	2	...	2	...
Pentamerus,	8	...	4	5
Porambonites,	3	...	2	1
Retzia,	3	...	...	3
Rhynconella,	26	...	10	17
Siphonotreta,	2	...	1	1
Spirifera,	5	...	1	4
Trematis,	1	...	1	...

LAMELLIBRANCHIATA.

MONOMYARIA.

Ambonychia,	6	...	5	1
Avicula,	16	...	5	11
Inoceramus?	2	...	2	...
Posidonomya,	1	...	1	...
Pterinea,	10	...	5	5

DIMYARIA.

Anodontopsis,	7	...	...	7

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Arca,	12	...	8	4
Cardiola,	3	...	1	2
Cleidophorus,	7	...	1	6
Conocardium,	3	...	2	1
Cypricardia,	2	...	1	1
Dolabra,	2	...	...	2
Grammysia,	4	...	...	4
Leptodomus,	2	...	...	2
Modiola,	6	...	6	...
Modiolopsis,	8	...	4	4
Mytilus,	7	...	2	5
Nucula,	13	...	7	6
Orthonota,	3	...	1	3
Psammobia ?	1	...	...	1
Sanguinolites,	10	...	...	10
Tellina ?	1	...	...	1
PTEROPODA.				
Conularia,	3	...	2	2
Ecculiomphalus,	3	...	2	1
Pterotheca,	2	...	2	...
Theca,	3	...	1	2
GASTEROPODA.				
Capulus,	2	...	1	2
Euomphalus,	16	...	10	6
Helminthochiton,	1	...	1	...
Holopea,	2	...	2	...
Holopella,	9	...	4	5
Loxonema,	2	...	...	2
Maclurea,	2	...	2	...
Macrocheilus,	1	...	1	...
Murchisonia,	14	...	9	6
Natica,	1	...	...	1
Nerita,	1	...	...	1
Patella ?	1	...	1	...
Phasianella,	1	...	1	...
Pleurotomaria,	10	...	6	4
Raphistoma,	2	...	1	1
Trochus,	8	...	6	2
Turbo,	10	...	6	4
Turritella,	4	...	1	3
HETEROPODA.				
Bellerophon,	13	...	8	6
CEPHALOPODA.				
Actinoceras,	3	...	1	2
Cyrtoceras,	3	...	2	1
Lituites,	11	...	6	5
Orthoceras,	54	...	24	33
Phragmoceras,	10	...	4	6

FISHES.

	No. of Species.	Lower Stage, (Cambrian.)	Middle Stage, (L. Silurian.)	Up. Stage, (U. Silurian.)
Onchus,	2	...	...	2
Plectrodus,	3	...	...	3
Sphagodus,	1	...	...	1
Thelodus,	1	...	...	1

On this list we may base some convenient numerical estimates. Assuming, as a general term of comparison, the number 1,000 to represent a total, we have the several groups of life represented in the Lower Palæozoic strata by the following numbers:—

Plants,	11	Mostly Marine.
Amorphozoa?	4	It is doubtful whether they be really such.
Foraminifera,	1	Many more may be expected.
Zoophyta,	142	
Echinodermata,	58	
Annelida,	23	
Cirripeda,	...	
Crustacea,	154 *	
Insecta,	...	
Tunicata,	...	
Bryozoa,	35	
Brachiopoda,	216 *	
Monomyaria,	40	
Dimyaria,	105	
Pteropoda,	11	
Gasteropoda,	100	
Cephalopoda,	93	
Fishes,	8	
Reptilia,	...	
Birds,	...	
Mammalia,	...	

And if, with the same assumed total (1,000), we count the species in the three several great groups, we have the subjoined result:—

In upper group (Upper Silurian),	496
In middle group (Lower Silurian,	485
In lower group (Cambrian),	19

Here we see numerically the most decided analogy between the upper and middle groups, the most positive contrast between them and the lower group. In regard to the former statement we may add that the numerical proportions for the different great groups of life are much alike through the upper and lower silurians. Thus in each case the bulk of the species is made up of zoophyta, crustacea, brachiopoda, dimyaria, gasteropoda, and cephalopoda, the proportions running thus in the silurian groups of strata:—

	Lower Silurian.	Upper Silurian.
Plants,	2	1
Amorphozoa,	3	1
Foraminifera,	...	1

	Lower Silurian.	Upper Silurian.
Zoophyta,	62	85
Echinodermata,	2	38 *
Annelida,	14	11
Crustacea,	111 *	47
Bryozoa,	10	24
Brachiopoda,	116	101
Monomyaria,	20	19
Dimyaria,	37	63
Pteropoda,	8	5
Gasteropoda,	67	48
Cephalopoda,	41	52
Fishes,	...	10

The most obvious contrasts are in the relative superiority of crustacea in the older group, and of echinodermata in the younger; fishes being as yet confined to the upper.

CAMBRIAN FOSSILS.

31

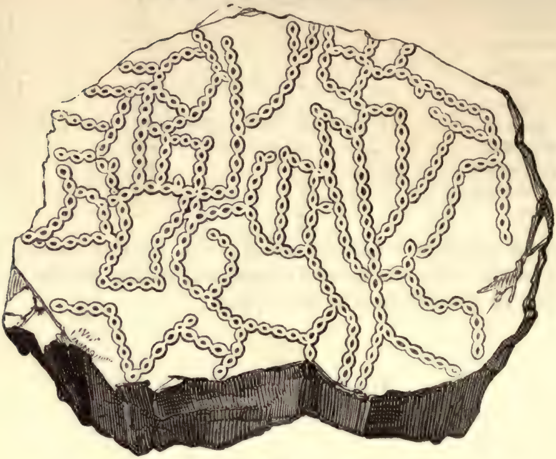
33

32

34

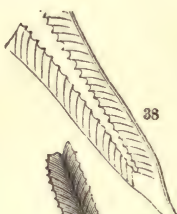
31 Oldhamia antiqua. Brayhead, Wicklow.
32 Hymenocaris vermicauda. Bangor, North Wales.
33 Olenus micrurus. North Wales.
34 Lingula Davisii. North Wales.

LOWER SILURIAN FOSSILS.



35

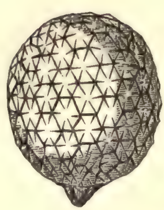
36



38

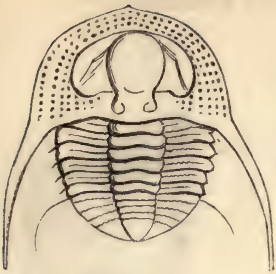
37

40a

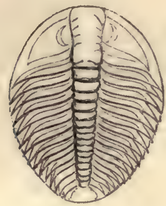


39

35 Halysites catenulata. 37 Diplograpsus pristis. 39 Echinosphærites aurantium.
36 Heliolites inordinata. 38 Didymograpsus murchisoni. 40a Nereites cambrensis.



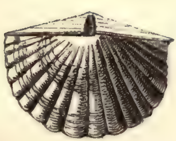
40*b*



41

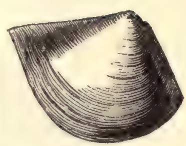
42

43

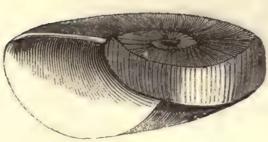


44

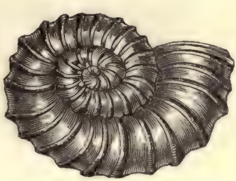
45



46



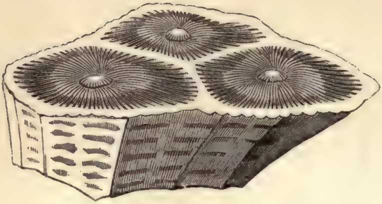
47



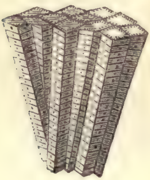
48

40*b* Trinucleus ornatus.
41 Ogygia Buchii.
42 Agnostus pisiformis.
43 Ptilodictya dichotoma.
44 Orthis flabellum.
45 Siphonotreta micula.
46 Ambonychia triton.
47 Maclurea Logani.
48 Lituites cornu arietis.

UPPER SILURIAN FOSSILS.

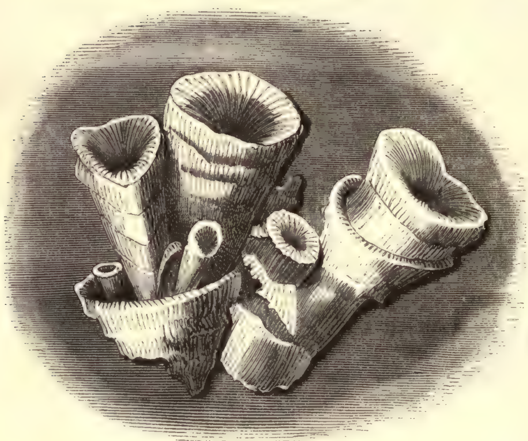


49



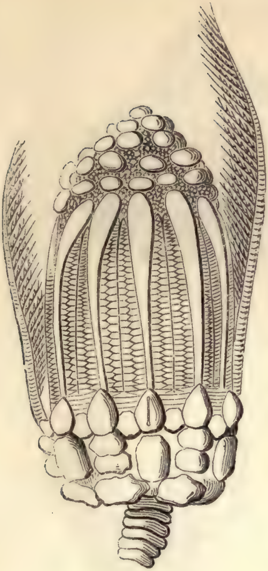
52

50

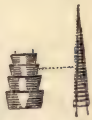


51

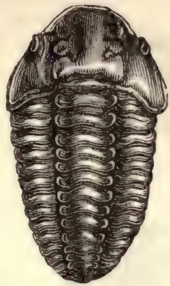
49 Arachnophyllum typus.
50 Cystiphyllum cylindricum (cut).
51 Cyathophyllum truncatum.
52 Favosites gottlandica.



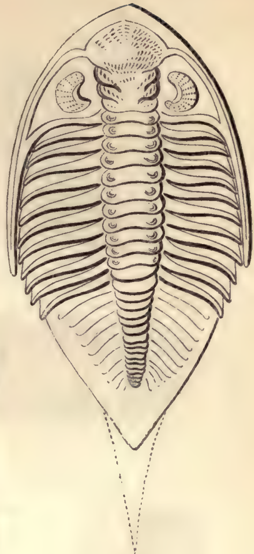
53



54a 54

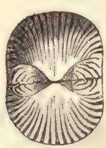


55

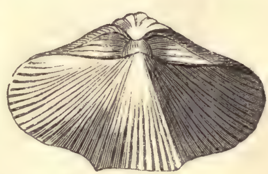


56

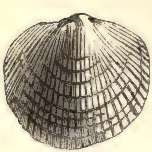
57



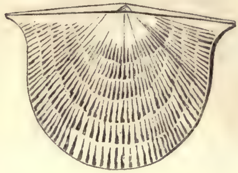
58



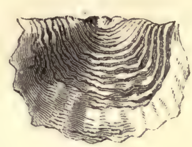
59



60



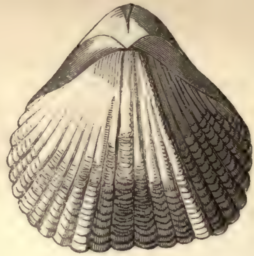
61



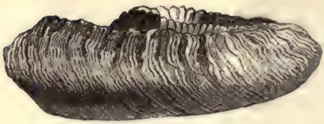
62

53 Eucalyptocrinus decorus.
54 Tentaculites ornatus.
54*a* Magnified view.
55 Calymene Blumenbachii.
56 Phacops caudatus.
57 Orbicula Forbesii.
58 Rhynconella Wilsoni.
59 Spirifera plicatella.
60 Atrypa reticularis.
61 Strophomena filosa.
62 Strophomena depressa.

63

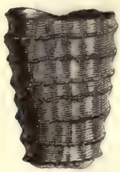


64

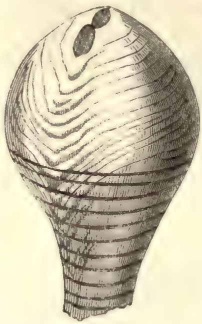


65

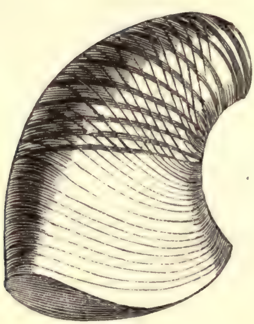
66



69



67



68

63 Pentamerus Knightii.
64 Pentamerus galeatus.

65 Euomphalus discors.
66 Conularia sowerbii.
69 Orthoceras annulatum.

67 Phragmoceras pyriforme.
68 Phragmoceras ventricosum.

CHAPTER VII.

MIDDLE PALÆOZOIC STRATA.

Physical Geography of the Period.—On passing to another great life period in the formation of the stratified crust of the earth, that during which the old red strata were deposited, the surface of the globe, as far as this can be known from observations so long posterior, was in a very different state from that which has been inferred to have been its condition before the deposit of the Lower Palæozoic strata. *Then* it is probable that little dry land existed, and perhaps most of the mechanical aggregates of the Silurian series were produced by agitations of the comparatively shallow waters of the ocean; but *now* many mountain ranges and groups may be traced dividing the ocean into seas and gulfs of various depths and unequal area, within which materials swept forcibly by inundations from the land were mingled with chemical precipitations and remains of life from the water. Thus the primary ranges of Scotland, England, Wales, and Ireland, the south of France, and the north of Germany, are in many parts enveloped in thick strata of conglomerates, sandstones, shales, coal, and limestone; and these deposits begin to assume more local characters, dependent on the varying physical conditions of the particular case.

Even in the limited area of the British islands, to which we shall mostly confine our special illustrations, the Middle Palæozoics exhibit two clearly marked types: one, the Scottish, Cumbrian, English, and Welsh type, of old red sandstone and red marls, with local conglomerates and concretionary limestones, poorly fossiliferous; a type found also in Man, and the north of Ireland; and the other the Devonian and Cornish type, of slates, compact limestones, red and gray sandstones, some of them rich in organic remains. This type occurs in many parts of Europe, and may be pretty well identified in North America, in Africa, &c.

Each of these groups of deposits is generally very distinguishable from those of the primary group; most remarkably so, where, as is generally the case, their accumulation was preceded by a great elevation of the older strata, but in several instances the change from the older rocks to the shales and sandstones of the superior group is very gradual (Herefordshire), and unaccompanied by violence, and the organic remains are often congeneric. It is not then a new creation, nor even a new system of nature, that we are called upon to examine, but another step in the scale of periodical operations, whereby the vacant planet was replenished with life, and fitted for the residence of man.

Scotland.—The old red sandstone is largely developed in Scotland, especially along the south-eastern edge of the Grampian mountains, and on the north-western side of the slate ranges of Lammermuir, from Dunbar to the coast of Ayrshire, as fully described by M. Boué. It appears in the valley of the Tweed, and about Jedburgh, Coldstream, Melrose, and Dunse. It forms in Arran the lower portion of one vast red sandstone series, the upper portion of which, not very different in any of its characters, is taken by Murchison and Sedgwick for the representative of the new red sandstone of England.

On the western side of Scotland the old red sandstone is found at many scattered points in bays and hollows of the mountains, and has received very good illustration from MacCulloch and the geologists above named. Along Loch Ness; about Inverness, Nairn, Forres, and Elgin; in almost the whole circuit of the Moray Firth; along the coast of Caithness, and occupying the whole of the north-eastern promontories to the Pentland Frith, strata of this age abound, and the Orkneys appear to consist chiefly of the same group of rocks, which also extend into Shetland along the coast from Sumburgh Head to Lerwick.

In the Orkneys the principal members of the group are dark, carbonaceous, and micaceous flagstones, with fishes of the genera dipterus, osteolepis, cheirolepis, &c. In Caithness, the same strata recur, covered by red sandstones, and resting on conglomerates.

Almost universally this red sandstone system, how various soever in thickness and in quality of composition, consists in all the lower portion, which rests upon the slate system, of a coarse conglomeritic sandstone, generally tinged red, full of fragments large and small, and rounded by attrition in water. This rock does not, like that of Cumberland, to which it is strongly analogous in composition, lie entirely in local hollows, but forms a continuous belt round nearly the whole primary district, where the border of this is distinctly seen, and rises into hills of considerable altitude, which are in this manner wholly composed of the ruins of the interior and still higher primary mountains. The contemplation of this remarkable rock in the vicinity of the beautiful lakes in the south-west part of the Grampians, can hardly fail to impress upon the attentive observer two propositions of the highest importance in geology. 1st, That the accumulation of these mountainous ruins of earlier rocks was caused by the violence of water, put into activity by the elevation of the primary rocks, and favoured in operation by the fractures which this operation produced in them. 2d, That since all these effects, the whole region of primary and derivative rocks has been again elevated, perhaps by a more insensible process, so as to raise the conglomerates to the height of 10,000 feet or more above the level of that sea in which they were formed.

According to the nature of the primary rocks in its vicinity, as remarked by M. Boué, the red sandstone conglomerate varies in composition. The degree of attrition to which the fragmentary masses which it includes have been exposed, is here different in different places; without doubt according to the degree and continuity of the aqueous action accompanying the disruption of the primary strata. Thus, on the banks of Lochness, at the Fall of Foyers, we find it a sort of granitoid breccia, with fragments slightly rolled of quartz, mica slate, red granites, primary limestones, &c. We might easily admit that this granitoid breccia is in some degree *metamorphic*, like certain breccias of Plutonic aspect in the slate district of Cumberland. The brecciated character, so remarkable at the Fall of Foyers, is speedily changed at a small distance into the usual aspect of a decided conglomerate.

Along the south-eastern edge of the Grampians, the composition of the conglomerate appears dependent in a high degree on the nature of the primary series on which it reposes. Near the granitic and porphyritic region of Aberdeenshire, quartz, felspar, porphyry, granite, with garnets, syenite, hornblende, compact felspar, are mentioned by Boué, with gneiss, mica slate, and clay slate. But in the district of Loch Katrine, where Plutonic rocks are less abundant in the slate system, the fragments consist almost wholly of mica slate and chlorite slate. In Oban we have observed that the rock contains not only masses of trap rocks, but that its base is in places almost wholly composed of the substance of those rocks reduced to sand. Along the Lammermuir ranges, which are composed of older slate and trap rocks, the conglomerates contain almost wholly slate fragments and boulders, and lie in hollows of the chain, very much as the contemporaneous deposits border the similar slates of Cumbria.

The inclination of the conglomerate strata is dependent on the configuration of the primary mountains, and there is no doubt that the stratification is for great lengths of country in irregular accordance with that of the older rocks; yet this dependence is chiefly observed along the lines parallel to the axis of elevation of the Grampians, and is even there liable to great exceptions. In the vicinity of Loch Lomond it succeeds clay slate; generally along the Grampians it rests on mica slate or chlorite slate; but along the Lammermuir hills on Cambrian and Silurian rocks.

Receding from the border of the mountains, the upper strata of red sandstone are found nearly free from pebbles, composed of laminæ of various quality, sandy or argillaceous; and sometimes, as in Perthshire, variously coloured. The Caithness graystones probably belong to this central division, or to a somewhat earlier date. To the upper part of the group belongs the remarkable series of Ganoid fishes, and the solitary reptile of Elgin, named by Mantell, Teler-

peton Elginense. Red sandstones accompany the coal of Dumfriesshire, and pass gradually into the limestone and coal series of the Lothians and Tweeddale, so that where, as in Arran, the limestone and coal are very thin, the whole has the air of a great continuous deposit, in which the carboniferous limestone and coal seams form merely the parting, not always traceable, between the old red and the new red sandstone systems. A geologist in the southern parts of Scotland, working without reference to other parts of the island, might think himself justified while including the carboniferous and saliferous systems in one general term, "the red sandstone system;" having, as subordinate groups, the mountain limestone and coal strata. More extended research and a sound view of palæontology would soon correct the error; we must, however, remember that what has been sometimes called new red sandstone, has appeared to later observers a part of the Rotheliegende, the lowest member of the Permian system.

Taking the most general view of the whole Scottish series of the old red, we find, with Miller,* in the north of the district,—

Upper Part.—Conglomerate sandstone, concretionary limestone. The principal and characteristic fish is Holoptychius nobilissimus. (Sil. Syst. pl. 2 bis.) (In other districts the conglomerate and limestone fail.)

Middle Part.—Gray sand and dark flagstone. The characteristic fish is Cephalaspis Lyellii. (Sil. Syst. pl. 1.)

Lower Part.—Red and light coloured sandstone, (perhaps here also the calcareous schists of Caithness and Orkney.)

Sandstone, clay, and calcareous nodules, with pterichthys, coccosteus, and other fishes. The basis of the series is generally a thick mass of rude conglomerate, in mountainous masses.

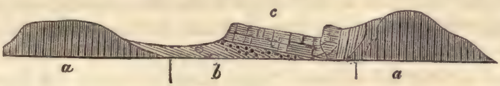
Old Red Sandstone Formation in England.

Origin of this Formation.—Proceeding now to the district of the English Lakes, we arrive at a case where the production of this rock is evidently modified by the effect of general convulsive movements. The slate rocks of Cumbria, exposed upon their recent elevation to enormous waste and degradation, were rolled to pebbles, which were collected into hollows or rude valleys, and reunited by a basis of red sandstone or red marl into vast irregular beds of coarse conglomerate.

In the Cumbrian District.—The limited tract of old red sandstone adjoining to the slate district of Cumberland and Westmoreland, lies principally on the eastern side, where it appears in patches, in Mell Fell, at Dacre Castle, Sedbergh, and Kirkby Lonsdale, and near Kendal. In all these situations it is a very coarse conglomerate, with a basis of red sandstone or red marl, filled with fragmentary

* See his excellent volume entitled 'Old Red Sandstone.'

masses, almost entirely derived from the neighbouring slate hills. Some of these fragments are quartz veinstone with micaceous iron ore; others are derived from the Coniston limestone. Each little patch of conglomerate is nearly confined to a particular valley, and seems, in fact, to have been accumulated by currents which in the ancient times of disturbance passed down that hollow. No organic remains have ever been found in this rock around the district of the Lakes, except in the rolled pebbles of Silurian slate or limestone. In some places the quantity of pebbles is diminished, and the red sandstone forms separate beds (Shapwells); in other places the red clay, alternating with blue and white layers (as at Kirkby Lonsdale),



70

a Silurian unconformed to, *b* Old Red, and *c* Carboniferous.

so closely resembles the new red marl, that nothing but the geological relations could determine the difference of the deposits. As might be expected in such a heterogeneous mixture, the beds and joints of the conglomerate are irregular, and it deserves attention that hitherto no mineral veins have been found to traverse it. Veins of calcareous spar occasionally divide it, and, what is remarkable, the pebbles are often split by these veins, as they are in the contemporaneous conglomerate of Oban in Argyllshire, and the more recent Nagelflue of Swisserland. Above the conglomerate in the valley of the Lune and other places we have red clays, with concretionary limestone, neither in great thickness, apparently conformed in position to the limestone series above.

It appears from these circumstances, that during the period of turbulence which succeeded the deposit of the slates in Cumberland, the waters of the sea had a particular tendency to deposit, near the shores, materials charged with red oxide of iron, and that the comparatively quiet process by which sandstones and clays were thus produced was liable to violent interruptions, and the products in consequence mixed with a vast quantity of fragments of the preconsolidated rocks, probably urged downwards to the sea along the lines of dislocated strata which had already begun to be excavated into valleys.

Deviating a little to the east, we find under Ingleborough and Penyghent, an old elevated Silurian shore, worn smooth by the sea action, and covered, not by old red, but by mountain limestone. A similar deficiency of old red occurs round the Cambrian rocks of Charnwood, and the Silurians of Nuneaton. There is no old red

above the Silurian limestones of Dudley, and hardly more than a trace of it above the Silurians of North Wales and Salop, from Conway to Coalbrook Dale. This absence may perhaps be in part due to unconformity; there may be *some* old red beneath parts of the limestone and coal of this tract named, but on the whole we think there is ground to admit that a large area of the Midland counties and the north of Wales is deficient of these rocks, an opinion which their evidently local character confirms, and even renders necessary.

In Wales.—Along the south-eastern and southern border of the slate district of Wales, from Coalbrook Dale, through Herefordshire, Monmouthshire, Glamorganshire, and Pembrokeshire, the old red sandstone formation is of vast thickness, fully developed, extensively spread out, composed of various definite parts, and regularly traceable through the country. Its boundary on the west is by Haverford-west, Caermarthen, Llandovery, Knighton and Ludlow. On the east it runs from near Cardiff, by the high district of Wentwood, Trelech, and Craig y Dorth, and by the Forest of Dean, which it encircles with a high boundary edge, the west of Mayhill, the Malvern and Abberley hills, to the Severn near Bewdley. Its thickness in Monmouthshire and Breconshire can hardly be estimated at less than 5,000 to 8,000 feet, but its lower edge is not always clearly distinguishable from the Silurian strata beneath. In fact, about Pont ar y llechau, near Langaddoc, the marly beds of the old red alternate with true Silurian strata, containing characteristic fossils. From the mountain limestone series above it is in general sharply defined. In the district of Tortworth, a yellowish sandstone appears along the junction line.

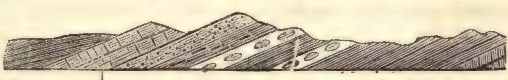
Monmouthshire, &c.—One of the best sections of the old red sandstone is afforded in the neighbourhood of Monmouth, beginning with the Kymin Hill, which is part of the lofty boundary of Dean Forest.

Here we perceive that the thick conglomerate rocks, full of quartz pebbles, remarkably analogous to some varieties of millstone grit, form the very cap of the whole system, and crown the hills with magnificent precipices and solitary crags. Below is a series of red sandstone rocks, productive of excellent flagstone, with one, or perhaps two, beds of a singular limestone, mottled with red, blue, green, and yellow, sometimes much mixed with clays, and always irregular. Though of argillaceous aspect, it is so nearly pure as to be burned to lime; and though apparently fragmentary, is really a very hard stone, fit for the roads. It contains no organic remains in this vicinity, but elsewhere few remains of Cephalaspis and other fishes occur in it. The lowest part of the section exhibits an extreme abundance of red marls with white and green bands, hardly distinguishable from those of the new red marl.

These characters accompany the range of the old red sandstone through the lower parts of Monmouthshire, and through Herefordshire, and part of Worcestershire, where the upper conglomerates are used as cyder millstones, and the limestone (called cornstone) is often employed on the roads.

This limestone, indeed, notwithstanding its apparently irregular and fragmentary character, is one of the most persistent layers that we are acquainted with, for it accompanies and characterizes the old red sandstone along nearly its whole course. In Caermarthenshire, it is particularly remarkable in the cliffs near Laugharne, from which specimens may be obtained not distinguishable from the 'gooseberry' stone of Monmouth.

Comparing these enormous masses of conglomeritic arenaceous and argillaceous rock, and this included limestone, with the older Silurian series, we find the main mineral distinction to be in the state of the iron which colours the rocks. Protoxide of iron is common in the older series, peroxide is prevalent in the newer group. As in many other cases, the gray oxide is accompanied by many, the red oxide by few remains of life. If life had been more abundant, the now irregular cornstones might have assumed the aspect of Wenlock or



71

a Silurian conformed to, *b* Old Red, and *c* Carboniferous.

Aymestry limestone. We shall find as we proceed, an exact verification of this suggestion in the Devonian type of the Middle Palæozoics. On the whole the older red series of Wales, and the course of the Wye and Severn, may be thus expressed in general terms :—

Upper Group.—*Conglomerates*, and sandstones of red, purple, and green hue, the pebbles, scattered in layers through masses of considerable thickness, are mostly of quartz, such as occurs abundantly in *veins* in the mica schist and gneissose rocks. The magnitude of the pebbles varies from an inch or two across to small white grains. Holoptychius nobilissimus occurs in this series.

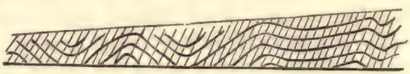
Middle Group.—*Flagstone series*, in great thickness, with partings of red shale and some irregular calcareous cornstones. In the country about Milford Haven this series is usually traversed by nearly vertical slaty cleavage. Cephalaspis is met with in this series.

Lower Group.—*Marl series*, mostly red, with pale and greenish bands, and irregular cornstone layers. White, dark gray, and yellowish sandstones appear in the lower part of the series, especially round the Mayhill district. (There is no coarse conglomerate in this part of the series comparable with that of the Cumbrian and Grampian chains.)

Passing from the districts of Mayhill and the Forest of Dean to the southward, we find the same general type of the old red in the country of Tortworth, on the banks of the Avon, below Bristol,* and in the anticlinal axis of the Mendip, near Banwell. But on the reappearance of the group in North Devon, it has a different aspect and composition.

North Devonian Type.

We are indebted to Sir H. T. de la Beche† for the first clear view of the succession of beds in the district of North Devon. The country is greatly contorted—the strata rising and falling in many steep anticlinals and deep synclinals, which run mostly from west to east. (See fig. 72.) In a survey which was made by the author



72

in 1839, he found the advantage of studying the great North Devon series in several groups as under‡ :—

Uppermost Group of Pilton.—This is a series of flaggy sandstones and shales, with interrupted and nodular deposits of limestone, full of fishes, much analogous to those found in the lowest part of the mountain limestone series, (to be noticed hereafter,) with which it might without much inconvenience be classed. The group below undoubtedly *belongs to the old red series.*

Morthoe Group.—Purple and gray schistose series, with interstratified gritstones, (slaty cleavage). No fossils.

Ilfracombe Group.—*Gray* argillaceous series, with limestone bands containing corals and shells, (slaty cleavage).

Martinhoe Group.—*Red*, claret-coloured, gray, and brown grits, with schists, &c., (slaty cleavage). No fossils.

Linton Group.—(1,000 feet thick,) mostly *gray* laminated grits and shales, with many fossils distributed in the mass, and collected in partially calcareous bands, (slaty cleavage occurs).

Foreland Group.—*Red*, gray, and claret-coloured grits and shales, (with slaty cleavage). No fossils.

Passing from North and South Devon, we cross wide regions of (peculiar) carboniferous rocks; granitic and porphyritic eruptions have much dislocated the strata, and it becomes difficult to

* See on these points De la Beche in Memoirs of Geological Survey, vol. i. 1846.
† Geological Report on Cornwall, Devon, and West Somerset. 1839.
‡ Palæozoic Fossils of Devon and Cornwall. 1841.

draw lines of exact contemporaneity in the rocks on the opposite sides of this one county. The following, which appeared to be the best section, was written down in Plymouth Sound, 1839,—dip southerly.

Group of *red* sandstone, and shales, with gray and purple shales (traversed more or less by slaty cleavage). In the gray shales and slates, corals, encrinites, and brachiopoda, are frequent.

Group of *gray* schists and subcalcareous beds, interstratified with what seem to be ash beds (thrown out by ancient volcanos), and recomposed traps. Fossils nearly as in the strata above.

Group of limestones, abundant at Plymouth, Torquay, &c. It is quite irregular, sometimes like a huge coral reef, in other places divided by shale partings, and toward the west thinning off to subcalcareous shales. Abundance of corals, brachiopoda, gasteropoda, cephalopoda, &c. Very slight trace of fishes.

Group of purple slaty rocks, some ash beds, the original lamination discoverable. No fossils yet observed.

If we class, as appears most advisable, the Plymouth limestone with that of Ilfracombe, we shall find the higher beds of South Devon by no means unlike the lower beds of North Devon. On the whole, the red element is diminished, animal life more widely diffused. The Plymouth limestone contains many Eifel fossils, and may be regarded as typical of the Middle Palæozoic system in Britain.

We omit the as yet unfinished survey of the Devonian beds through Cornwall, where it appears that some traces of Silurian strata below them are satisfactory to Murchison.*

The old red series occurs in the Island of Arran, north of Brodick Bay, conglomeritic and arenaceous, accompanied by thin red limestone, with the usual crinoidea and brachiopoda of the mountain limestone, and thin gritstone and shale (coal measures) accompanied by stigmaria. (See Ramsay's Guide to Arran.)

In the Isle of Man, we see the same formation principally in steep cliffs north of Peel and about Castleton; in the latter case resting on Silurian or Cambrian schists, overlaid by limestone, and traversed by trap dykes.

Ireland offers what seems to be a large development of brownish old red sandstone in the district east of Lough Erne, and south of Omagh, where it is arenaceous and conglomeritic, and rests on lower Silurian and Cambrian. About Castlebar, and extending from Newport to Lough Conn in Mayo, is a large tract of brown red sandstone and conglomerate, said to be *unconformably* below the mountain limestone.† In the central tracts of Ireland, Mr. Griffith mentions and maps old red sandstone in the elevated tracts of Slieve Bloom,

* Siluria. † Griffith in Reports of British Association, 1843, p. 48.

the Inchiquin, Beruagh, Keeper, and Galtee mountains. Other tracts occur in the promontory of Dingle, and the vicinity of Killarney and Bantry. But the largest area, and probably the most certainly ascertained to belong to the old red, is that which surrounds Cork, Youghal, Dungarvan, and Waterford, everywhere covered by the lower members of the great limestone series—everywhere extremely similar to the old red sandstones and marls of Pembrokeshire, and like them traversed by slaty cleavage, the angle of inclination of the cleavage to the plane of the strata often varying from bed to bed.*

The middle Palæozoic series, considered with reference to the two types now described, appears to have assignable geographical characters. The "old red sandstone" type prevails everywhere in the British Isles north of the Bristol Channel; the Devonian type spreads farther southward and eastward in Europe, being recognized in Brittany, between lower Silurian and carboniferous rocks; in the district of Boulogne, which appears to have the upper parts of the series only, and on the Rhine and Moselle, where the whole series of North Devon appears to be almost exactly represented by parallel deposits.

According to Murchison's latest view,† we may group the Rhenish and Belgian type of the old red series in the following manner:—

Upper Devonian.—A series of schists characterized very extensively by the presence of a bivalvular crustacean (cypridina), and when limestones interlaminate the schist, by goniatites and clymeniæ. It prevails in Nassau, in Saxony, and Thuringia. It may be paralleled by the clymenian limestone of Petherwin, and the upper beds of North Devon.

Eifel Limestone.—The great central calcareous mass, equivalent to that of Plymouth, and probably to that of Ilfracombe, full of corals, crinoidea, brachiopoda, gasteropoda, cephalopoda, and trilobites, and some of the old red fishes. Stringocephalus Burtini belongs to this rock.

Middle Devonian.—Schists, with sandstones and some lenticular limestones. Calceola sandalina belongs to this group.

Lower Devonian.—Sandstones with slaty schists, and some impure limestone. This contains large spiriferæ, some species of phacops, and the curious pleurodictyum problematicum.

On the whole, the resemblance of this series to that of Devonshire is very satisfactory.

Parting from the mountainous regions of the Taurus and the Hundsruck, and the streams of the Lahn, Rhine, and Moselle, we find in the old volcanic region of the Eifel, the Devonian strata much disturbed and even inverted, and this character, which is continued in Belgium, has caused much difficulty to M. Dumont.

* This observation was reported to the British Association Meeting in Cork, 1843.
† Siluria, p. 367

Two-thirds of the area of the chain of the Pyrenees is composed of clay slate, which appears to exhibit many varieties of texture and aggregation, the coarser kinds being dark green, micaceous, or granular, aluminous or siliceous. It appears to be mainly of the Devonian age. Frequently these slates alternate in very thin layers with limestone, in which case a number of calcareous fibres crossing the slate, but not the limestone, give the mass the peculiar appearance of schiste rubanné; limestone abounds with this slate series, and is either compact, slaty, or granular, always more or less metamorphic. It contains crinoidal and zoophytic fossils, "goniatites," and a few other shells, and some are found in the alternating slates. Anthracite in small quantities is mixed with the slates; quartzose, felspathic, and greenstone rocks alternate with them. Most of the metallic products of the Pyrenees are found in the slaty system. (Charpentier.)

Spain possesses in the Sierra Morena, the Asturias, Sierra Cantabrica, sandstones, shales, and limestones, red and gray, and richly fossiliferous, as Mr. Pratt and De Verneuil have proved.

In Germany, the Devonian rocks are, on the whole, more extended than the Silurian. The Hartz limestones and slates, described by M. Bonnard, Roemer, and others, appear to be of Devonian age. Devonian forms appear in calcareous rocks in the Thuringerald, Franconia, and Voigtland. In Franconia, especially at Elbersreuth, we have Devonian limestones, with many clymeniæ and goniatites, comparable to those of Petherwin, near Launceston.

The basin of Bohemia, with Prague for its centre, affords a complete Silurian series, the uppermost form offering some marked Devonian *analogies*.

In the Riesengebirge, south of Breslau, a Devonian limestone occurs with fossils; the same is observable in Moravia.

Near Warsaw, a small tract of Devonian rocks with fossils occur.

In Russia, though not of great thickness, the Devonian beds spread very widely in a country of moderate undulation. Here we have the interesting and important fact of the occurrence together of the ichthyoid life of the old red type, Asterolepis, Glyptosteus, Dendrodus, Holoptychius, Pterichthys, with the molluscous life of the Devonian type.* From the Valdai hills and the Baltic provinces to the White Sea, these rocks offer many interesting points of study,—the sandy rocks more particularly yielding fishes, the argillaceous and calcareous bands being more prolific of orthides, rhynconella, atrypæ, &c. In the very lowest beds, goniatites occur. It appears to be *unconformed* to the Silurian rocks,† and to be free from Plutonic irruptions, except on the flanks of the Uralian chain.

* Austen in Geological Proceedings.
† Murchison, Geology of Russia, Siluria, chap. xiv.

In the Strensfiord, west of Christiania, the old red sandstone has the character of conglomerate.*

The upper groups of the series of New York State and Canada, given by Mr. Hall, are now generally admitted to belong to the Devonian age. They are in perfect conformity, both to the Silurian below, and to the Carboniferous rocks above. They contain many Devonian fossils. A similar succession has been recognized in South America, by D'Orbigny.† Perhaps the Falkland Isles contain such fossils.‡

The Cape of Good Hope yields Devonian fossils:§ they have been collected in Central Africa by Dr. Overweg.

In Asia, the Himalaya, and perhaps most of the great chains, contain Silurian and probably Devonian representatives, and characteristic fossils of the latter groups have come to Europe from Kevangsi, south of Shanghai, and from Itier, north of Canton.

Finally, Australia gave to Count Strzelecki, Devonian, as well as other Palæozoic forms. Metallic veins are rare in the old red sandstone rocks, but veins of crystallized earthy substances occur frequently. Carbonate of lime traverses it at Kirkby Lonsdale; sulphate of barytes near Monmouth and South Sannox in Arran; sulphate of strontian occurs in it, near Inverness: and asbestus in Kincardineshire. (Boué.)

PLANTS.

FILICINÆ.

Cyclopteris Hibernicus, .	1	......	......	Sth. of Ireland
Actinophyllum plicatum,‖	1	Woolhope district,	......	......
Lepidostrobus ? ‖ . .	1	Woolhope district,	......	.. ...

AMORPHOZOA.

Scyphia turbinata, . .	1	......	South Devon,	......
Steganodictyum, . .	2	Cornwall,	......	......

FORAMINIFERA.

Occur in the limestones of Cannington Park and South Devon.

ZOOPHYTA.

ZOANTHARIA.

Acervularia, . .	5	......	South Devon,	......
Alveolites, ...	4	......	Do.	......
Amplexus, . . .	1	......	Do.	......
Arachnophyllum, . .	2	......	Do.	......

* Murchison, Siluria, p. 319.
† Voyage dens l'Amerique Maridionate, 1842.
‡ Darwin.
§ Bain in Geol. Proceedings.
‖ These two plants are found at the very base of the old red, or on the very top of the Silurian.

Battersbya, . . .	1	......	Do.	Sth. of Ireland.
Campophyllum, . .	1	......	Do.	......
Chorophyllum, . .	1	......	Do.	......
Cyathophyllum, . .	8	......	Do.	......
Cystiphyllum, . .	2	......	Do.	......
Emmonsia, . . .	1	......	Do.	......
Endophyllum, . .	2	......	Do.	......
Favosites, . . .	3	......	North and South Devon,	......
Hallia, . . .	1	......	South Devon,	......
Heliolites, . . .	2	......	Do.	......
Metriophyllum, . .	1	......	Do.	......
Pachyphyllum, . .	1	......	Do.	......
Petraia, . . .	4	......	North and South Devon,	......
Pleurodictyum, . .	1	......	South Devon,	......
Sarcinula, . . .	1	......	Do.	......
Smithia, . . .	1	......	Do.	......
Spongophyllum, . .	1	......	Do.	......
Strephodes, . . .	3	......	Do.	......
Stromatopora (Caunopora)	5	......	Do.	......

ECHINODERMATA.

CRINOIDEA.

Actinocrinus, . .	1	South Devon.	
Adelocrinus, . . .	1		Brushford, ND.
Cupressocrinus, . .	1	South Devon.	
Cyathocrinus, . .	8	4 S. Devon,	4 N. Devon.
Hexacrinus, . .	3	South Devon.	
Taxocrinus, . .	1		North Devon.

BLASTOIDEA.

Pentremites, . .	1		North Devon.

CYSTOIDEA.

Echinosphærites, . .	1	South Devon.	

ARTICULATA.

ANNELIDA.

Tentaculites, . .	1	South Devon, (Salter).	

CRUSTACEA.

Bronteus, . . .	1	South Devon.	
Cheirurus, . . .	1	South Devon.	
Harpes, . . .	1	South Devon.	
Homalonotus, . .	1	Do.	
Calymene, . . .	4	2 So. Devon,	1 Petherwin, 1 Croyde, &c.
Phillipsia, . . .	1	South Devon.	
Trimerocephalus, . .	1	South Devon.	
Cypridina, . . .	1		Petherwin.
Pterygotus, . . .	1	Forfarshire.	

BRYOZOA.

Ceriopora,	1		Pilton, Brushford.
Fenestella,	4	3 So. Devon,	1 Petherwin.
Glauconome,	1		Croyde, Pilton.
Hemitrypa,	1	Barton, S.D.	
Ptilopora,	1	Plymouth. Barton.	
Retepora,	1	Maidstone Bay.	

BRACHIOPODA.

Athyris,	7	Merton, Ogwell Hope, Plymouth, Barten, Torquay	Petherwin.
Atrypa,	4	South Devon,	Petherwin.
Calceola,	1	South Devon.	
Chonetes,	4	South Devon,	Linton, Brushford.
Cyrtia,	1	South Devon.	
Leptæna ?	8	South Devon. Cornwall.	
Orthis,	12	South Devon,	Petherwin. Linton.
Pentamerus,	3	South Devon.	
Producta,	4	Plymouth,	Pilton, Brushf.
Retzia,	1	South Devon,	Croyde.
Rhynconella,	19	South Devon,	Petherwin, Baggy Point.
Spirifera,	27	South Devon,	Barnstaple, North Devon.
Strophalosia,	2	Plymouth,	Petherwin,&c.
Terebratula,	3	South Devon.	......

MONOMYARIA.

Avicula,	8	1 So. Devon,	4 Petherwin, Polter, &c.
Aviculopecten,	6	1 So. Devon,	7 No. Devon.
Pterinea,	3	1 So. Devon,	2 No. Devon.

DIMYARIA.

Anodonta ?	1		1 Ireland.
Axinus,	1		1 No. Devon.
Cleidophorus,	1	1 Torquay.	
Conocardium,	2	South Devon.	
Corbula,	1	South Devon.	
Cucullæa,	5		North Devon.
Cyclas,	1	Scotland.	
Cypricardia,	1		North Devon.
Leptodmus,	1		North Devon.
Megalodon,	3	South Devon.	
Modiola,	2	South Devon,	Petherwin.

Mytilus, . . .	1	South Devon.	
Nucula, . . .	4		North Devon.
Pullastra? . . .	2	South Devon,	North Devon.
Sanguinolaria? . .	2		North Devon, Cambria, &c.
Sanguinolites, . .	2		North Devon.

GASTEROPODA.

Capulus, . . .	2	South Devon.	
Euomphalus, . . .	5	4 So. Devon,	1 N. Devon.
Loxonema, . . .	7	Newt. Bartn.	Petherwin.
Macrocheilus, . .	7	South Devon,	1 N. Devon.
Murchisonia, . . .	5	South Devon,	Peth. Brushf.
Natica, . . .	2	......	N. Dev., &c.
Nerita, . . .	2	South Devon.	
Pleurotomaria, . .	6	South Devon,	North Devon.
Turbo, . . .	2	South Devon.	

HETEROPODA.

Bellerophon, . . .	5	South Devon,	North Devon.
Porcellia, . . .	1		Petherw., &c.

CEPHALOPODA.

Clymenia, . . .	11	South Devon,	North Devon.
Cyrtoceras, . . .	13		
Goniatites, . . .	9	South Devon,	North Devon.
Nautilus, . . .	2	South Devon,	Petherwin.
Orthoceras, . . .	10	South Devon,	N. Devon, &c.

FISHES.

Acanthodes, . . .	1	Elgin, Gordon Castle.
Actinolepis, . . .	1	Elgin.
Asterolepis, . . .	3	Elgin, Caithness.
Bothriolepis, . . .	2	Elgin, Nairn.
Byssacanthus, . .	1	Herefordshire.
Cephalaspis, . . .	4	Herefordshire, Forfarshire.
Cheiracanthus, . .	5	Orkney, Gamrie, &c.
Cheirolepis, . . .	6	Orkney, Cromarty.
Climatius, . . .	1	Balruddery.
Coccosteus, . . .	7	Orkney, Cromarty.
Conchodus, . . .	1	Scat Craig.
Cosmacanthus, . .	1	Elgin.
Ctenacanthus, . .	1	Abergavenny.
Ctenoptychius, . .	1	Scotland.
Dendrodus, . . .	4	Morayshire.
Diplocanthus, . .	6	Morayshire, Orkney.
Diplopterus, . .	4	Orkney, Caithness, Gamrie.
Dipterus, . . .	1	Orkney, Caithness.
Glyptolepis, . . .	3	Elgin, Gamrie.
Glyptopomus, . .	1	Perthshire.
Gyroptychius, . .	2	Orkney.

Holoptychius,	7	Orkney, Elgin, Perthsh., Brecon.	
Homothorax,	1	Perthshire.	
Lamnodus,	3	Elgin.	
Onchus,	2	Herefordshire.	
Osteolepis,	5	Orkney, Caithness.	
Pamphractus,	1	Perthshire.	
Parexus,	1	Balruddery.	
Phyllolepis,	1	Clashbinnie.	
Placothorax,	1	Elgin.	
Platygnathus,	2	Orkney, Perthshire.	
Pterichthys,	10	Orkney, Cromarty, Gamrie.	
Ptycacanthus,	2	Herefordshire, Monmouthshire.	
Stagonolepis,	1	Elgin.	
Tripterus,	1	Orkney.	
		REPTILIA.	
Telerpeton Elginense,	1	Elgin,	1

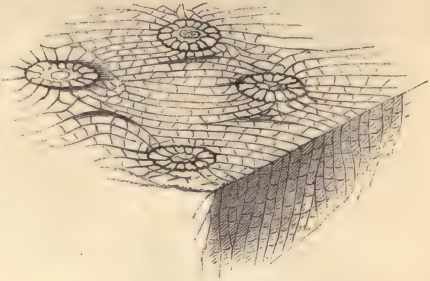
Analyzing the middle Palæozoic groups of life on the same plan as that used for the Silurian, we have the following proportions to 1000.

	Prop. to 1000.		Prop. to 1000.
Plants,	7	Bryozoa,	22
Amorphozoa ?	7	Brachiopoda,	225 *
Foraminifera,	2	Monomyaria,	40
Zoophyta,	123	Dimyaria,	71
Echinodermata,	40	Gasteropoda,	104
Annelida,	2	Cephalopoda,	106
Cirripedia,	0	Fishes,	221 *
Crustacea,	28	Reptilia,	2
Insecta,	0	Aves,	...
Tunicata,	0	Mammalia,	...

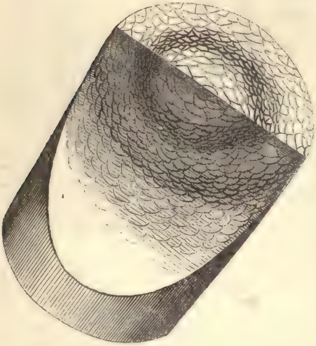
NOTE.—Comparing this with the tables for the Lower Palæozoic strata, we perceive the same general abundance of zoophyta, brachiopoda, gasteropoda, and cephalopoda; but the crustacea which had begun to diminish in upper Silurians are here still more reduced; fishes, which in those deposits were few, are here extremely numerous, and reptiles for the first time come into notice. The brachiopoda still retain their absolute numerical superiority. (*See for comparison, page* 128.)

MIDDLE PALÆOZOIC FOSSILS.

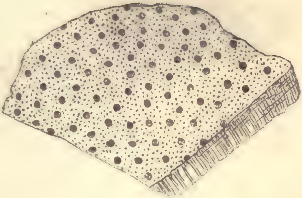
73



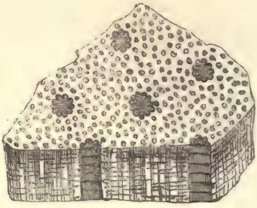
74



75

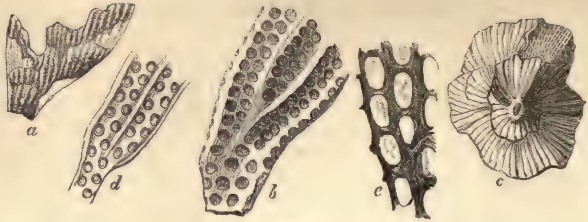


76



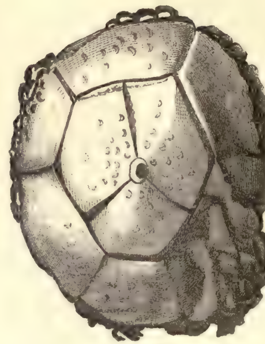
76*a*

73 Arachnophyllum Hennahii, natural surface.
74 Variety of the same cut across.
75 Cystiphyllum vesiculosum, cut to show the structure.
76 Heliolites pyriformis.
76*a* Magnified section.



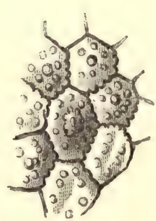
77

78



79

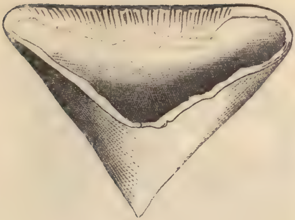
78*a*



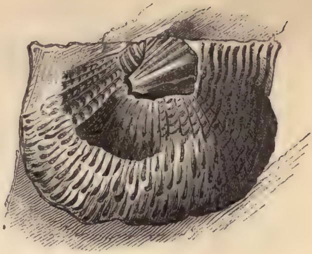
79*a*

77 Hemitrypa oculata.
a Small specimen.
b External face of *a* magnified.
c Centre of a large specimen.
d External face of *c*.
e Internal face of *c*.

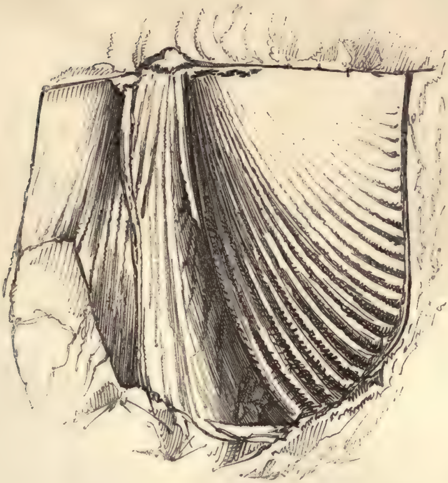
78 Stromatopora polymorpha.
78*a* Magnified section.
79 Hexacrinus interscapularis
79*a* The apex.



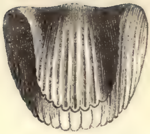
80



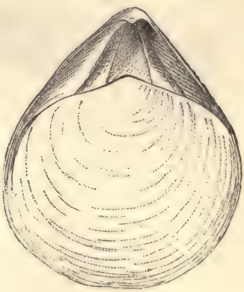
81



83

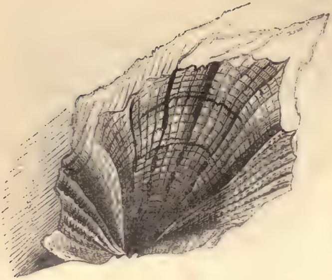


82



84

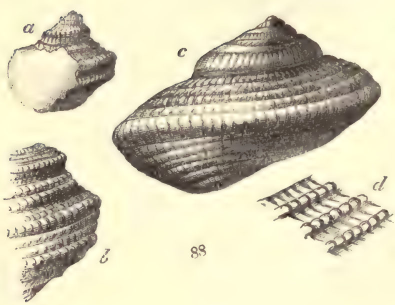
80 Calceola sandalina.
81 Producta caperata.
82 Rhynconella cuboides.
83 Spirifera gigantea.
84 Stringocephalus Burtini.



85

86

87



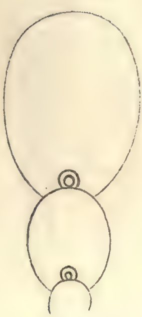
88

89

85 Avicula spinosa.
86 Cucullæa? trapezium.
87 Murchisonia spinosa.

88*a* Pleurotomaria aspera (*b*) magnified.
88*c* Pleurotomaria aspera, variety *d* magnified.
89 Cyrtoceras tredecimale.

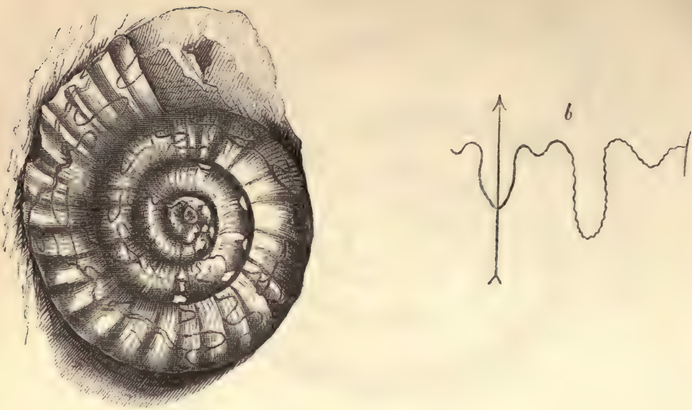
90



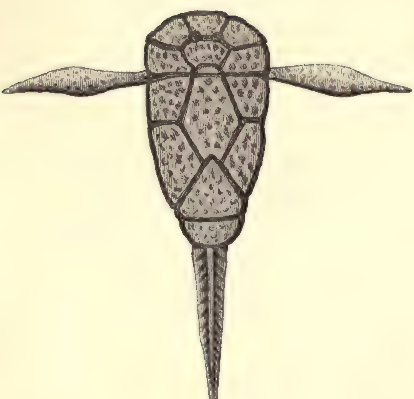
a

b

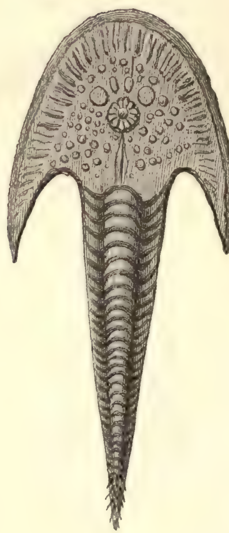
90 Clymenia lævigata. (*a*) Cross section. (*b*) Edge of a septum.



91



92



93

91 Goniatites insignis. (*b*) Edge of a septum.
92 Cephalaspis Lyellii.
93 Pterichthys Milleri.

CHAPTER VIII.

UPPER PALÆOZOIC STRATA.

Carboniferous System.

Divisions of the System.—In England the carboniferous system, when fully expanded, admits of division into the following groups, which, however, are not to be found together in every district:—

e. Coal formation (upper group).
d. Millstone grit (supramedial group).
c. Yoredale Rocks (medial group).
b. Scar limestone (submedial group).
a. Shales, &c. (lower group).

The five groups here admitted easily and naturally collect themselves into two greater assemblages, the upper one specially carboniferous, the lower one specially calcareous, but in each of the many districts of Britain where these valuable strata occur, some local peculiarity is observable which often disturbs the classification. The millstone grit connects itself by marine fossils with the Yoredale rocks in the north of England, and with the coal measures by its plants, and thus has the air of a transition group, which may for convenience be sometimes joined to the lower, sometimes to the upper series, and occasionally be treated alone, and the lowest member, in some places calcareous, in others argillaceous, or arenaceous, varies much in its affinities to the limestone. It has sometimes been referred to the red sandstone series below. In Yorkshire, the limestone series begins to be intermingled with coal, sandstones, and shales; in the northern parts of Northumberland these two series are intimately blended. The millstone grit is 800 feet thick in Yorkshire and Derbyshire, but dwindles away to a mere band in many parts of the south of England.

There is nothing peculiar in this: we shall find exactly similar phenomena among the superior formations. In fact, it is certain that among all the formations, the minute distinctions of strata are mostly local, and even the formations themselves, however extensive, are limited within the circuit of the anciently elevated mountains. The whole series is in Britain conformable to the red sandstone below, and was united to that rock by Mr. Conybeare.*

In describing this series, we shall confine ourselves principally to the British Isles.

* Geology of England and Wales.

Carboniferous System—Its Geographical distribution in England and Wales.

Passing over the anticlinal ridges of the Lammermuirs, we come to the great connected carboniferous system of Tweeddale, Northumberland, Durham, Yorkshire, Derbyshire, and Nottinghamshire, which spreads westward to Cheshire, and Lancashire, Westmoreland, Cumberland, and Dumfriesshire; a district 200 miles in length and on the average 60 miles in breadth. Berwick, Kelso, Langholm, Ecclefechan, Brampton, Brough, Shap, Cockermouth, Whitehaven, Dent, Kendal, Ulverstone, Lancaster, Preston, Liverpool, Manchester, Newcastle-under-Lyne, Cheadle, Nottingham, Bolsover, Conisborough, Aberford, Ripon, Richmond, Ferryhill, and Tynemouth may be noted as on or near to the border of this great field. In it all the five divisions already stated may be recognized.

A long but narrow and broken band of the carboniferous system is traced from Anglesea, by the Orme's Head, the sides of the Vale of Clwyd, and the country of Halkin, Mold, Wrexham, to Oswestry, and from hence we may pass by the detached coal fields of Shrewsbury, Coalbrook Dale, Billingsley, the Clee Hills, Dudley, Coventry, to the Ashby de la Zouch field, which is not far distant from Nottingham, on the great northern run of coal. These coal fields appear now separated at the surface by new red sandstone, but they may be, and probably will be, hereafter in some degree connected by subterranean operations, by perforations through the new red, of which Lord Dartmouth's trial near Birmingham is a successful precursor. In none of these districts is the series of rocks so thick or so varied as in the larger tract to the north. The fullest development is in Flintshire, where limestone (*b*) is succeeded by a representation of millstone grit (*d*), and the coal series (*e*). This may be seen again in less compass in the Clee Hills.

Farther south we have the great range of carboniferous rocks in South Wales, extending about 90 miles from St. Bride's Bay in the west, to Pontypool in the east, but interrupted by old red sandstone (on which the whole rests), at the mouth of the Towy. The breadth, at a maximum, is about 20 miles. The series consists of the following parts in the extreme west of the district:—

e	Coal measures, . . .	11,000 feet thick!
d	Millstone grit, . . .	300 feet.
c?	———————	
b	Scar limestone,* . . .	1,900 feet.
a	Lower shales, &c.,* . . .	500 to 800 feet.

Separated by old red sandstone, about 20 miles, we have the coal

* I recall with much pleasure the measuring of this and many other sections in South Wales, with H. T. De la Beche, in 1841.

field of Dean Forest resting on carboniferous limestone. The series has the same terms as that of South Wales, but is not so thick in any part.

e Coal, ...	—
d	270
c	146
b	480
a	165

Similar remarks apply to the small coal tract of Newent, and the more considerable field of Kingswood, both in Gloucestershire, the latter area continued across the Avon into Somerset. The section at Bristol following the Avon gives us the following general terms :

e Coal, ...	—
d Millstone grit, . . .	950 feet.
c? ———— . . .	400 ...
b? Carboniferous limestone, . .	1438 ...
a Lower shales, &c., . . .	500 ...

We can give no accurately measured section of the peculiar carboniferous system of Devon, where in general terms we have most frequently,

e, *d* } Culm and sandstones.

c, *b*, *a* } Thick shales and thin dark limestones.

The district stretches from east to west 50, and from north to south 35 miles, occupying on the whole a great broad, much undulated and contorted synclinal.

Carboniferous System of England.

The carboniferous limestone series (and millstone grit where the association is useful to the description).

Mountain or Carboniferous Limestone Formation.

The carboniferous limestone is a rock of which the history must principally be studied within the limits of the British Islands, for it is nowhere else so much or so variously developed. Its romantic rocks border many of the most beautiful valleys of the south-west of Scotland, northern and central England, and encircle the wide primary regions of Wales. In Ireland, as Mr. Weaver observed, this limestone is the prevalent and characteristic rock in most of the counties, except Derry, Antrim, and Wicklow. (See Griffith's Map.)

The romantic channel of the Meuse runs for a considerable dis-

tance about Namur and Liege, in a very remarkable range of carboniferous limestone, along the northern side of the primary slates of the Ardennes, and is prolonged eastward to the German side of the Rhine, near Dusseldorf, and continued westward (beneath a wide deposit of chalk) to the neighbourhood of Boulogne. The coal deposits of Poland are based upon dark limestones of the same age as the carboniferous limestone of England, but in general the coal fields of the centre and south of France, of Saarbruck, of Saxony, Silesia, &c., appear to be devoid of this rock; but Murchison mentions its occurrence in the north-east of Bavaria and in Bohemia. It abounds in North America, supporting coal and anthracite.

It has been before remarked, that the carboniferous limestone presents itself with a very different aspect in the northern and southern counties of England. In Somersetshire, Gloucestershire, Shropshire, South Wales, North Wales, Derbyshire, and Leicestershire, this rock appears an immense, nearly undivided, calcareous mass, perfectly defined below by a hard contrast with the old red sandstones or Silurian strata which support it, and as distinct above by the abrupt covering of sandstones and shales which accompany the coal.

Very rarely indeed in the southern counties, as in the eastern edge of the Forest of Dean, are any beds of sandstone interpolated among the lowest strata of limestone; and it is only by a few unimportant partings of shale that the upper portion is at all assimilated to the incumbent series. The toadstones which irregularly interlaminate the thick limestones of Derbyshire are of igneous origin, and it is not, in proceeding northward, till we arrive in the valley of the Ribble, that any decided alternation of mechanical deposits breaks into distinct groups the strata of carboniferous limestone. From this point northward, almost in the ratio of distance, to the banks of the Tweed, the limestone becomes more and more divided by beds of sandstone and shale, accompanied by ironstone, fossil plants, and coal; and thus, under Ingleborough we have a nearly undivided calcareous mass 400 or 500 feet thick; but at Aldstone Moor no less than twenty different limestones, amounting altogether to 470 feet, obscured by the interposition of no less than 1,686 feet of sedimentary strata.

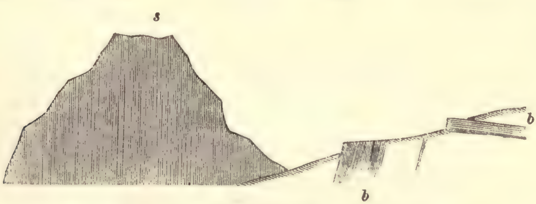
Farther north these mechanical admixtures increase in amount, while the calcareous strata diminish, and at length, in the northern parts of Northumberland, the limestone district has become a valuable coal field.

To embrace the subject in its most interesting point of view, we shall commence our account of the carboniferous limestone with a description of its characters in the "Penine Alps," which border the western parts of Yorkshire and Durham, and the eastern parts of Cumberland and Westmoreland, and we shall connect therewith

the analogous arches of limestone, which begird the primary district of the Cumbrian lakes. Taking this as a type of the formation, we shall be able to compare with it the other localities in the British Isles and on the continent of Europe.

This tract of country has been, for different objects, partially described by Professor Sedgwick and other geologists, and their views, whether published or not, will be recognized in the following summary. The Cumbrian slates are surrounded for three quarters of a circle, from Egremont to Ulverston, by a belt of limestone, which reposes indiscriminately upon the lower slate near Loweswater, the middle slates near Ulswater, the upper slates from Shap to Ulverston, and the old red conglomerate at the several points of Dacre, Sedbergh, Barbon, Kirkby Lonsdale, and Ulverston.

The south-eastern part of this circular belt forms part of a long range of limestone cliffs facing the west from Ingleborough to Tindal Fell, defined by one continuous line of elevation nearly 1,000 yards in height. Prodigious transverse dislocations occur at these points; that at the northern end ranges east and west, and causes an immense depression to the north, after which the limestones range north-east through Northumberland; that at the southern end ranges west-south-west and east-south-east, and causes an equally striking depression to the south, after which the limestones show themselves locally, and in much disturbance, as far south as Clithero.



94 Dislocated limestones at the edge of the Pennine chain.
b Scar limestones on the east. *s* Silurian on the west.

From the high western escarpment before mentioned, the strata sink with a very regular inclination eastward or south-eastward, and are exposed in the valleys of the South Tyne, Derwent, Wear, Tees, Greta, Swale, Yore, Ribble, Wharfe, Nid, and Aire, bordering those streams with some of the boldest and most picturesque rock scenery in England.

The grand natural section of Ingleborough and Penyghent presents us with the following series of rocks belonging to the carboniferous formations, to which letters are affixed in the order already assigned:—

			Feet.
d	Group above the limestone, commonly called millstone grit series	Alternations of sandstone and shale, with bad coal on Penyghent	100
		Millstone grit of Ingleborough	60
		Alternations of sandstone and shale	100
c	Upper belt of limestone	Thin limestone 8 feet; Shale 10; Main / Great limestone 60	78
	Alternations principally of shales and sandstones, some of them flagstones, with thin limestones,		300
b	Great scar limestones with calcareous conglomerate beds at bottom		400

This series rests on slate rocks (Lower Silurian).

Proceeding northward from Ingleborough we arrive in Wensleydale or Yoredale, and find the section modified as under:—

			Feet.
d	Millstone grit series. Above the limestone.	Coarse and fine sandstones, shales, and COAL; Coarse, fine, and slaty sandstones, shales, cherty beds, and COAL; Millstone grit of Ingleborough, shales, cherts, and COAL	700
c	Upper limestone belt.	Thin limestone, sandstone, shale; Main or twelve fathom limestone; Shales, sandstones, and COAL, underset limestone	200
	Flagstone series	Alternations of flagstones of various quality, in great abundance, with shales, COAL, hard gritstones, and three or four strata of limestone, from 6 to 30 feet thick. The black marble of Dent is nearly at the base of this group	500
b	Scar limestones	Limestones of great thickness, with partings principally of shale	500

The series is incomplete, other limestones existing below.

Here it will be perceived the group *d* has become divided into distinct parts; and the calcareous portions of *c* are also more defined and more important; the upper part, *b*, has assumed that character of a decidedly double belt, which henceforward distinguishes it for a great distance to the northward.

Our next station will be taken in Swaledale.

				Feet.
d	Millstone grit series	Coarse gritstones, shales, finer sandstones, shales, and COAL	600	800
		Variable series of thick shales, with sandstones and COAL, and local interpolations of limestone and chert	200	
c	Upper limestone belt.	Limestone	3	252
		Shale, &c.	63	
		Main or twelve fathom lime	72	
		Grit, chert, shale, and COAL	96	
		Underset lime	18	
	Flagstone series	Variable alternations of gritstone, flagstone, and plate, with three or four limestones from 6 to 30 feet thick		340
b	Scar limestones	Of great thickness, but only partially exposed in the bottom of Swaledale		

The groups *c* and *d* have now become more complicated, and require further division as compared with the Ingleborough section, and thus we are gradually conducted to the still more developed series of Teesdale and Aldstone Moor, as described by Forster:—

			Calcareous beds. yds.	ft.	in.	Other deposits. yds.	ft.	in.
d	Mill-stone grit series.	Alternations of sandstone (coarse and fine), and shale				25	1	0
		1. Felltop lime	1	1	6			
		Alternations of laminated and other sandstones, shales, ironstone, and COAL				109	2	8
c	Upper limestone belt.	2. Limestone	3	0	0			
		Alternations, plate, &c., with COAL				16	2	0
		Limestone	21	0	0			
		3. Parting				10	0	0
		4. Limestone	0	1	6			
		Sandstone, and shale, and COAL				23	1	0
		5. Underset limestone	8	0	0			
	Flag-stone system.	Sandstone and shale (Nattriss Gill Hazle)				17	0	0
		6. Limestone	3	0	0			
		Sandstone and shale				15	1	6
		7. Limestone (5 yards)	2	1	6			
		Sandstone and shale				10	0	0
		8. Scar limestone	10	0	0			
		Thin alternations				15	0	0
		9. Cockleshell limestone	0	2	0			
		Alternations				5	2	6
		10. Limestone (single post)	2	0	0			
		Alternations				20	0	0
b	Scar lime-stones.	11. Tyne bottom limestone	8	0	0			
		Alternations in the upper part of which the "Whin sill" (igneous) occurs, (20 to 40 yards thick)				24	2	6
		12. Jew lime	8	0	0			
		Alternations				8	2	6
		13. Little lime	6	0	0			
		Alternations,				30	0	0
		14. Smiddy lime	10	1	6			
		Sandstone,				4	0	0
		15. Limestone	8	1	6			
		Alternations				7	0	6
		16. Robinson's lime	7	0	0			
		Alternations				4	0	0
		17. Great limestone, Melmerby scar	44	0	0			
		Alternations and COAL				8	0	0
		18. Limestone	4	0	0			
		Alternations				55	0	0
		19. Limestone	2	1	6			
		Alternations and COAL				73	2	0
		20. Limestones	6	0	0			
		Alternations				78	0	0
			156	2	0	562	0	2

It is probable that even this section does not show us the full depth of the series.

95 High Force, Teesdale. A waterfall in prismatic "whin sill" over limestone.

96 Caldron Snout, Teesdale. A waterfall in subprismatic whin sill.

We were some time occupied in endeavours to ascertain *exactly* the line which in the Aldstone section separates the groups *b* and *c* of Yorkshire, and the above result is very near the truth.

Combining together the preceding statements, we have the following results in total thickness; the sign + signifies that the thickness is incomplete:—

Group.		Penyghent.	Wensleydale.	Swaledale.	Aldstone Moor.
d	Millstone grit series (incomplete series).	260+	700	800	409
c	Upper limestone belt.	80	200	250	247
	Alternations, or flagstone system........	300	400	250	304
b	Scar limestones........	400	250+	120+	1196

In the following table the relative proportions of the calcareous and other deposits are estimated:—

Group	Penyghent.		Wensleydale.		Swaledale.		Aldstone Moor.	
	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.
d	?	260	?	700	10	790	4	405
c	70	10	100	100	93	157	97	150
	30	270	50	350	40	210	54	250
b	400		150+	-100	80+	- 40	313	883
	500	540	300+	1250+	223+	1197+	468	1688

We must remark that this comparison is imperfect, because the sections are not in each case defined above or below by the same beds; in order to obtain a fairer numerical comparison, we may omit altogether the beds above the upper limestone belt, and, on account of its incompleteness, the fourth group in Wensleydale and Swaledale. We shall then have the following corrected scale:—

	Penyghent..		Wensleydale.		Swaledale.		Aldstone Moor.	
	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.	Lime-stones.	Other deposits.
Upper limestone belt....	70	10	100	100	93	157	97	150
Flagstone series	30	270	50	350	40	210	54	250
Scar limestones...........	400	—	—	—	—	—	313	883
	500	280					464	1283

Had we, instead of Penyghent, chosen Great Whernside for our section, we should have had the limestone of these groups about 1,000 feet, and the other deposits less than 200 feet: and if we had taken a section in Northumberland, instead of Aldstone Moor, the limestones would have been less than 200 feet, and the other deposits probably nearer 1,000 feet. The principal changes, as we proceed northward, appear to happen in the lower part of the limestone group, which loses its individuality, by admitting between its beds a constantly increasing quantity of mechanical admixtures, and at

length becomes a subordinate feature in a country which has the characters of a coal field. We shall now trace the course of the carboniferous limestone round the Cumbrian mountains, and through other parts of England.

Range of the Mountain Limestone.—The submedial, or as we also name it "scar limestone" group, passes westward from Ingleborough by Kirkby Lonsdale, Burton, and Cartmell to Ulverstone and Dalton; extending northward to Kendal. (See Smith, Geological County Maps.) This group everywhere possesses the almost wholly calcareous character which it bears in Ingleborough. On the south of Ulverstone, it is covered by the intermediate grit and plate series, with traces of coal, and a more extensive deposit of this kind south of Kirkby Lonsdale, yielding useful coal and flagstone, is again overlaid by the upper belt of limestone and afterwards by the millstone grit series towards Lancaster.

97 Gordale Scar, near Settle. In scar limestone.

Under Wild Boar Fell, on the borders of Yorkshire and Westmoreland, the scar limestones begin to exhibit, in consequence of dislocations, a double escarpment, the western branch passes off by

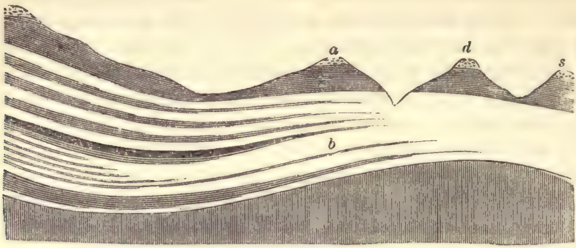
Ashfell, Orton, Shap, and Lowther, to the Eamont, and continues by Greystoke Park, Hesket, Ireby, and Cockermouth to Egremont. These limestones alternate in their lower parts with red sandstone, by some geologists referred to the old red, and diminish in thickness westward. These alternations are referred to the lower group (*a*). They are overlaid by deposits of the grit and shale series near Shap, Hesket, Newmarket, and Bolton, but from Workington to Whitehaven the thick and abundant coal seams probably belong to the ordinary coal series (*e*) above the millstone grit. There is perhaps unconformity here between the coal measures and the limestone, a case very rarely observed in England.

Agreeably to what has been said before, the scar limestones, in passing through Northumberland, become continually more and more subdivided by interpolations of sandstone, shale, and coal, till on the sea-coast north of Belford, a part of this series contains no less than thirteen bands of limestone, (121 feet in total thickness,) separated by many times their thickness of sandstone and shale, and under the whole lie workable seams of coal. The character of the surface of all the western and north-western part of Northumberland corresponds to this change of the component strata. Instead of the beautiful green pastures which delight our eyes amidst the calcareous dales of Derbyshire and Yorkshire, wide, heathy, and boggy moorlands overspread the surface of sandstones and shales, and we seem to wander in a region of barren coal measures rather than on the range of the thickest carboniferous limestones. This may serve to explain the seeming anomaly in Mr. Greenough's map, where this unquestionably carboniferous tract was formerly represented as distinct from any of the strata in the British section. Mr. Smith coloured the whole space as a coal tract.

On the contrary, in proceeding southward along the Ribble, we find the scar limestones in great force about Clithero, surmounted by a considerable mass of shales and sandstones, corresponding to the shale and grit series of Ingleborough; above these, in Pendle Hill, appears the diminished upper belt of limestone, and, over all, the millstone grit series, here also occasionally yielding coal. Hence to Derbyshire the scar limestones lie too deep to be seen, and the upper belt of limestone appears to be extinguished; so that this part of the western boundary of Yorkshire is occupied by a vast thickness of the millstone grit series and the medial flagstone series, without any disclosure of the subjacent limestones, even in the deeply excavated valley of Todmorden.

In Derbyshire, putting out of the question the irregular interpolations of igneous rocks, called toadstone, we have the scar limestones more than 750 feet thick, surmounted by shale, with their alternations of sandstone, *limestone*, ironstone, &c., 500 feet, and the hills are crowned by bold ranges of millstone grit, and its accompanying sandstones, 360 feet in thickness.

See fig. 98, which expresses in general terms the *method of variation* of the carboniferous limestone and millstone grit series of the grand Pennine chain.



98 Section of the lower and middle parts of the Carboniferous system in the Pennine chain.
d Millstone grit. *c* Yoredale series. *b* Scar limestone. *s* Silurian.

South of Derbyshire we have no longer the same remarkable masses of strata (*c*, *d*) interposed between the scar limestones and the proper carboniferous sandstones and shales. The limestone occurs in North Wales, as in Anglesea, across the centre and on the northern coast, about Beaumaris, and on the Menai Strait. It forms the conspicuous promontory of Orme's Head, runs under Denbigh and Ruthin on the western side of the vale of Clwyd, shows in limited and disturbed patches on the east of that vale,—forms the picturesque and elevated country west of Holywell, Mold, and Wrexham,—turns round the magnificent cliffs of Eglwyseg to overlook the beautiful Vale of Llangollen, and continues its course southward to an almost sudden termination at Llanymynach, near Oswestry. In this range there is only a narrow trace of old red sandstone below it, as in the cliffs of Eglwyseg. This whole range represents the scar limestone or submedial group of the system (*b*).

Slightly exhibited under the coal of the Clee Hills, it resumes its grandeur on the edge of the Forest of Dean, and there discloses, from beneath, the lower group (*a*) in sections above Mitchell Dean, as well as the supermedial group (*d*) all round the forest. De la Beche* has given the materials for the short summary which follows :—

e Coal above all.			
d Millstone grit, consisting of sandstone, shale, and conglomerate.			
c Medial band	Gray and red limestones and marls..........	25 feet	201 feet.
	Red sandstone, with thin shales and marls, some hæmatite veins........................	176	
b Scar limestone, red, gray, and blue, with hæmatite..........		480	
a Lower group of shales and limestones, mostly dark, with remains of fishes..		165	

* Memoirs of Geological Survey, vol. i., p. 127.

The upper part of the old red series, containing gray, yellow, and red sandstones and marls, with scatterings of quartz pebbles, &c. Plants analogous to some in North Devon occur in this series. On the Avon it is thicker. Round a great part of the South Wales coal field, we find the lower series (*a*) rising to importance, and continually thickening to the westward; so that, in the district of Gower, a part of Pembrokeshire, its thick shales and thin limestones constitute great cliffs and scars, full of fossils having analogies to those of the Upper Devonian series. In Ireland, especially in the southern parts, this analogy is still more apparent and extensive.

The limestone tract along the Meuse is evidently of the same era as the limestone of Derbyshire and Monmouthshire, and continually recalls to the delighted voyager the beauties of the Derwent and the Wye, but the strata above it are with difficulty compared in detail with those of any part of the English basins.

In still greater thickness we find the carboniferous limestone groups pass round the "basin" of the South Wales coal field, under "millstone grit," and over the old red sandstone. At the western extremity of the range, and on the south side (West Angle Bay), we find by the measures of the Geological Survey, 1841, the lower series of shales, limestones, and sandstones reddish and yellowish, in many alternations, 584 feet thick. The whole group is marked at frequent intervals by beds of coprolites and *fish remains*, and almost at the bottom are remains of plants. In Caldy Island, also on the south side of the "basin," the scar limestone (*b*), the lower shales and old red sandstone appear in magnificent cliffs, and disclose the whole series of life, and mechanical and chemico-vital deposits. The scar limestone almost unmixed with any sedimentary matter is 1,895 feet thick, the lower beds from 400 or 500 feet, being literally full of *crinoidea* and strophomenæ, and the upper 1,400 or 1,500 feet, yielding, besides other fossils, distinct *coral bands*. The lower series (*a*) is here about 400 feet thick, and as in the previous example, very rich in fish remains, crinoidea, strophomenæ, and spiriferæ.*

If we now add to these sections the known thicknesses of the superincumbent strata corresponding to the millstone grit and coal measures, we shall have the following general section of the carboniferous system in South Wales :—

e Coal formation—no limestone (plants)...........................	11,000 feet.
d Millstone grit (called Farewell Rock), &c. (plants)...........	300
c Yoredale rock? (Gower shales).	
b Scar limestones (corals, &c.)..	1,900
a Lower shales, limestones (fish beds, &c.) (a few plants)......	400
	14,000

Or more than two and a-half miles in thickness.

* De la Beche in Memoirs of the Geological Survey, vol. i.

The thickness here assigned, however, is not attained by any one member of the group in all parts of the basin or its borders. The limestone series (*a*, *b*) in particular, is reduced to far smaller thickness in the north side of the basin, and as a whole, the series grows thinner toward the east. Perhaps it is thickest in almost all particulars about Swansea, and in the picturesque district of Gower, where in a limited tract, the Yoredale shales (*c*) appear to have a thickness of 1,600 feet! *

The section of lower carboniferous strata on the Avon, near Bristol, has been long known as the best in the south of England, and has been often copied and described, and more than once measured. The most detailed account of the thicknesses is contained in the Geological Survey's Memoirs.† In general terms it may be thus collected:—

d Millstone grit—here mostly a hard reddish gritstone, the grain often almost confluent as in what are called quartzites and quartz rocks	950 feet.
c Alternations of limestone, red or gray, compact or granular, with shales, red, dark, or gray, and *sandstones*, red or gray. Fossils through a great part of the mass. Producta gigantea abundant near the base.. about	400
b Scar limestones—gray, reddish, mottled, brown and black, compact, shelly, crinoidal, and oolitic, in beds varying in thickness, and partially divided by *shales*................................	1,438
a Lower series, enclosing many alternations of limestones and shales, the former often black, brown, yellowish, sometimes impure, and in one part charged with fish remains and cyprides in abundance ("the bone bed").........................	500

The upper part of the old red series shows yellow and gray sandstones and marls.

Proceeding southward from the Bristol district, we may notice the sections of the limestone series in Mendip, raised on an anticlinal axis, which displays the old red sandstone. The upper part of the series not being well seen, we have the following general view:—

b Scar limestone, in many parts very cherty, the chert being in nodules of irregular forms, and lying in the midst of the beds of limestone, which have various colours, and are, as at Bristol, often oolitic. Corals often cherty. Hæmatite occurs as in the limestone of Bristol and Dean Forest.

a Lower series of shales with thin limestones.

Thus, from the Tweed and the mountains of Northumberland, to the precipices of the Avon and Mendip, we have traced the course of the five-parted carboniferous system, and have acquired a knowledge of the much varying bed of the sea in that large space. South of the Mendips we enter a quite different local series of these beds,

* De la Beche. Mem. of Geol. Survey, vol. i.
† Vol. i., p. 113.

with little coal, and little limestone; a series as unlike the great carboniferous groups of the other side of the Bristol Channel as is the old red sandstone of Devon from the old red of Breconshire and Scotland. The series of carboniferous deposits in North Devon has the following general aspect about Barnstaple and Bampton (no slaty cleavage):—

e, *d* Upper part, anthracitiferous, and containing ironstone, and by these characters agreeing with the coal deposits of Pembrokeshire. This is in general a gritstone series, with plants of the coal formation.
c? Coddon Hill cherts, black, and shales of considerable but variable thickness.
b Limestone and black shale, with posidoniæ, goniatites, &c.
a Black shale group.

Similar in general character is the series of South Devon strata about Trescott and Lew Trenchard:—

d The gritstone group of Central Devon.
c? Upper shale group—dark shales, carbonaceous grits and shales, equal to the Coddon Hill series.
b Calcareous group—limestone of dark colour, and irregular bedding with shales. (Posidoniæ).
a Lower shale group, with few fossils.
(No slaty cleavage).

It appears then, on the whole, that the main conditions of the five divisions of the carboniferous system can still be recognized in the at first view anomalous groups of Devonshire, their special analogy pointing clearly to the extreme west of South Wales, where, as in Devonshire, the old red series is subject to slaty cleavage, and in one part, about Haverford-west, the diminished limestone is barely recognizable.

Having thus compared in the most general point of view the component groups of the carboniferous limestone and millstone grit series in different localities, and ascertained the method of variation which they observe, we shall endeavour to describe some of the principal characters of these several groups.

Scar Limestones.

The carboniferous limestone, though by no means of one uniform aspect or chemical composition, possesses, nevertheless, a certain range of mineralogical characters which are scarcely to be recognized in any of the other secondary calcareous deposits. It is usually a nearly pure carbonate of lime, of a grayish or even very blue tint, of considerable hardness, and imperfect conchoidal fracture. Some of the varieties are very dark coloured, and even quite black (Swansea, Abergavenny, Kilkenny, Derbyshire, Yorkshire), but the latter commonly contain a minute admixture of argillaceous and bituminous

matter. Many varieties exhale a fetid odour on being rubbed or bruised. In Derbyshire, and generally along the Yorkshire and Westmoreland ranges, the scar limestones contain considerable beds of a granular and even brecciated limestone capable of being employed as good freestone, and some layers in Derbyshire and Westmoreland appear almost wholly composed of crystalline grains, and contain magnesia. A crystalline variety in Derbyshire is mixed with red oxide of iron. In the country about Burton in Kendal, and Clifton, near Bristol, the stone is often decidedly oolitic, and even exhibits considerable variety in this respect. The lower layers which rest upon the slate in the Craven mountains, at Kendal, and near Penrith, are filled with large and small boulders of the slate, so as to become a real conglomerate.

But the most decided characters of these rocks are the organic remains, all of which are different from those of the strata above. The prodigious abundance of productæ, spiriferæ, terebratulæ, and other shells, of lamellated corals, and above all, of crinoidal remains, will almost always enable even the tyro to pronounce on the identity of the mountain limestone. Crinoidal remains, in particular, are so excessively abundant in certain parts as to constitute fully three-fourths of the mass of the rock.

Chert Beds and Nodules.—A remarkable character is imparted to vertical sections of this rock in the Mendip hills, in several parts of Derbyshire, and the neighbourhood of Clithero, by nodules of chert embedded in the limestone, often at regular distances, like the flints in chalk. A very striking section of this kind is seen in Vallus Bottom, near Wells. This chert is usually of a dark gray, or even black colour, but occasionally it is white, and in general its colour corresponds to that of the limestone beds which contain it. It rarely contains any organic nucleus, and thus differs from a large proportion of the flint nodules in chalk, with which, in the manner of its production, and in its relations to the calcareous rocks, it seems otherwise very analogous. The cherty layers in green sand and coralline oolite are also analogous instances, and we have hereafter to notice a similar character in a certain portion of the magnesian limestone. Proceeding northward, as the limestones are divided, these chert nodules are less plentiful, though in Coverdale, in Yorkshire, they abound, and at Glenwhelt, on the Roman wall, shells of the genus Bellerophon have been detected in a very dark chert embedded in the limestone there.

Chert Beds.—The curious circumstance of conversion, as the miners say, or rather substitution of beds of chert for beds of limestone, generally at the top of the rock, is noticed in most parts of the limestone tract in England and Wales; and very often it happens, as in Westmoreland, that the corals are converted to siliceous matter in the

midst of a block of limestone. It is probable that the rottenstone of Dentdale, Swaledale, Aldstone Moor, and Derbyshire may be occasioned by decomposition of the shale limestone near the surface. (Farey and Johnston.) A specimen collected by the author at Aldstone Moor in 1820, which as to substance is a kind of rottenstone, contains several fossils of the limestone series, especially a very small species of trilobite. Similar facts are common in Derbyshire and the Yorkshire dales.

Bitumen in solid masses lies very frequently in the beds of the scar limestone, and enters the cavities of productæ, orthocerata, &c.; as at Castleton, and near Clithero. In a liquid as well as solid state it will be noticed under the next division of the carboniferous strata.

Physical Geography.—The surface of the country which is occupied by this rock in England is remarkably characteristic. Having been exposed to many repeated convulsions, it is thrown up to considerable altitudes, and placed in a great variety of positions favourable for the exhibition of the changes wrought on it by the atmosphere and streams. It is principally to the hardness and comparative durability of this rock, conjoined with its stratification and extensive system of *joints*, that we owe the grand ranges of vertical escarpments, which begird with a perpetual fortification the sides of the dales of Yorkshire and Derbyshire. Often, indeed, the wasting effect of the elements is sufficient to excavate vertical rents and to insulate the great prisms of the rock which, especially in Dovedale and other parts of Derbyshire, give the most romantic features to the valleys, while the same effects upon the high scars in Yorkshire and Westmoreland show like towers and bastions projecting from the wall of rocks or among the green herbage which has spread around them.

Swallow Holes.—Frequently upon broad surfaces of limestone, especially where it alternates with shale, we find ourselves suddenly stopped by a deep vertical pit in the rocks, worked by some little rill, or even by the mere gathering of rains, an effect more frequently observed in the course of streams, which, like the Calder in Cumberland, traverse the ranges of this rock. These "swallow holes," as they are justly called, often serve to mark out uninterruptedly for miles the lines of limestones, whose actual edges may be obscured by the sliding of other matter over them.

Swallow holes sometimes communicate downwards with internal caverns, which are nowhere so abundant as in the lower or scar limestones. It is to them we must refer the numerous caverns of Mendip Hills, in Somersetshire, the rocks of Clifton, the Forest of Dean, the celebrated caverns of Staffordshire and Derbyshire, and those beneath Ingleborough and Penyghent, in Yorkshire. Farther north, along the Pennine chain, where these limestones grow thinner, the caverns become less numerous, and in the same proportion the phenomenon

of underground streams is rarely observed. This remarkable phenomenon is evidently dependent on the thickness, as well as on the open joints and absorbent surface of the rock, and examples of the same kind occur in various other thick calcareous strata of England, as the oolites and chalk, as well as in the Jura limestone or oolite of Germany and France. It is to the same causes that we must ascribe the extraordinary strength of the springs which issue as clear as crystal from the openings of this rock; but, being highly charged with carbonate of lime, soon deposit along their channel abundance of tufa. The herbage upon this limestone is usually short, elastic, and nutritious, and of a lovely green, which contrasts strongly with the bluish aspect of the moist surfaces of the shales, and the brown tints of the heathy moorlands of millstone grit.

Yoredale Series—Lower Part.

In Derbyshire.—The shale and grit, or flagstone series above the scar limestone, is called in Derbyshire the limestone shale. It is about 500 feet thick, and consists principally of black or brown rather durable shale, forming a very wet soil, and causing land slips of great extent beneath the millstone grit summits. Mam Tor, the "Shivering Mountain," near Castleton, exhibits these characters very decidedly. The shale, however, is interstratified to a great extent, and with a considerable regularity, with thick rocks of fine-grained micaceous gritstone, of excellent quality for building, and, as we have observed, generally at the bottom of this rock, with good durable micaceous flagstone, very similar to that in the more recent coal strata. Some less regular sandstone beds, called "cankstone," approach very nearly to the nature of the ganister or calliard rocks of the coal strata. Mr. Farey, who considers these interpolations as *anomalies*, calls by the same name the very characteristic beds of black argillaceous limestone which lie in this shale, at Ashford, near Bakewell, and near Ashborne, and produce lime fit for water cement. The frequent contortions of the limestone and shale are noticed by Mr. Farey as very remarkable. Ironstone balls lie in bands in this shale, a few impressions of fossil plants have been collected, and very thin coal seams observed, not worth the expense of the fruitless trials in search of them. Liquid bitumen is mentioned at several points in connection with the limestones in this shale.

In Yorkshire.—This description of the Derbyshire limestone shale would apply with scarcely a varying sentence to the broad argillaceous strata which cover the thick limestones of Craven. The same abundance of shale, occasional interpolations of sandstone, ironstone, and laminated beds of dark limestone, the same traces of coal and liquid bitumen, the same contortions, may be traced in Craven and in Wharf-

dale. More divided by sandstones and limestones, the same shale is recognized in Pendle Hill, Ingleborough, and Penyghent. The locality most remarkable for the abundance of liquid bitumen is at Flasby in Craven, where Mr. Preston has excavated a considerable quantity of the black argillaceous limestone, and found it associated with abundance of goniatites sphericus, besides large orthocerata and the curious bivalves, now known by the name of Posidonia. The nautili are generally inverted or have their cavities filled with liquid bitumen, and small solid lumps of the same substance are likewise met with. This, amongst others, is one strong reason for believing that the darkness of colour of these limestones and shales is due to the admixture of carbonaceous matter.

99 Millgill Force, near Askrigg.
A waterfall in Yoredale Rocks, the upper part limestone, the lower part shale.

By a communication of Sir Philip Egerton and Lord Enniskillen, to the Geological Society, we have learned that the lower coal shale, as it has been termed in the western Irish coal fields, is precisely

analogous, not only in mineralogical characters, and in its geological position between the mountain limestone and the true coal measures, but also in its organic remains, to the "limestone shale" of Derbyshire and Craven. The same goniatites, the same posidoniæ, (Bronn,) and other characteristic fossils occur in these far separated districts; and in general, so strict is the accordance in all respects, that no geologist accustomed to the strata of the north of England could fail to recognize in the mountains above Enniskillen an exact analogy with Ingleborough and Great Whernside.

100 Gale Force, near Hawes.
A waterfall in Yoredale Rocks, the upper part limestone, the lower part shale.

Pennine Chain.—In the further continuation northward of this series of shales, sandstones, and limestones, the limestones, as before observed, thicken, the alternations of sandstone and shale therefore become more frequent and decided, coal seams intervene, and the whole assumes the character of a complicated coal and limestone deposit. It is possible, in tracing the different limestones enumerated in this series, to assign characters of local permanence. Thus the beds most remarkably stored with crinoidal reliquiæ are those of the "main lime," in Pendle Hill, Ingleborough, Cam Fell, &c.; the black limestone of Whalley, Kirkby Lonsdale, and Dent is almost wholly deprived of them, like the same beds in Derbyshire; productæ abound on the top of the main lime, lithodendra are often plentiful in the beds below it, and one thin bed of limestone, at Aldstone

Moor, receives, in consequence of the nature of its organic contents, the name of cockleshell lime. Chert lies frequently on the top of the main lime and underset or four fathom lime beneath it, as well as on the top of the little lime or crow lime above it. Slaty sandstone yielding flagstone occurs both in the alternations under the main line, and in those still lower between the underset and scar limestones. In one or other of these places in the section, flagstones are dug in Swaledale and Yoredale, in Graygarth Fell, near Kirkby Lonsdale, and Garstang, and it is probable that the flagstones of the north of Derbyshire belong to the same epoch. In some of the very hard sandstones which occur in this series in Swaledale, (like the cankstone of Derbyshire,) stigmariæ and other fossil plants occur, but in general the coal seams are not accompanied by many vegetable remains.

A kind of rottenstone, as before mentioned, occurs in this series in Dentdale and at Aldstone Moor, and probably in many other places is produced from the decomposition of the limestone.

The shales of this tract are usually dark, close, and fissile, and traversed by extremely long straight joints ranging north by west and south by east, east-north-east and west-south-west, dividing the rock into rhomboidal prisms. They often contain nodules of ironstone. A very remarkably indurated flinty shale, fit for use on the roads, which occurs in Swaledale and Yoredale above the main limestone, is called "black beds."

The sandstones vary as to fineness of grain, and some of them, in their progress through Northumberland, assume such a coarseness of aspect, as to be in fact undistinguishable from the "millstone grit" of the next group.

The marine fossil remains are almost wholly confined to the limestones and the cherts which sometimes replace them and the shales, but the few vegetable remains belong wholly to the sandstones and to the coal.

Yoredale Series—Upper Limestone Belt.

The only additional remarks which we shall make on this portion of the strata refer to the remarkable variation of character by which the limestone in several places is gradually changed to or suddenly replaced by chert. Thus in Swaledale the united thickness of the underset chert and underset lime (the former being uppermost) is nearly constant, but the thickness of each is extremely variable. In like manner in Wharfdale, about Kettlewell, the underset lime, just before it expires entirely under Great Whernside, is represented only by hard chert, and the main lime of the same district, before it thins out and dies away, becomes remarkably cherty, both by the change of whole beds

and the introduction of chert nodules. Theré appears some reason to attribute this effect, in one case, to the operation of a vein, while in others it may, perhaps, be properly viewed as indicating merely the suppression of the calcareous deposit, independently of the siliceous. It must be owned, however, that the notion of miners, and that first suggested to the geologist, agree in assigning the effect in some instances, even independent of dykes or veins, to a real chemical conversion of the nature of the rock since its deposition.

Millstone Grit Series.

Mineral Composition.—The difference of composition between the coarse sandstones which abound in this part of the series, and those of finer grain which alternate with the limestones below and the coals above, is rather apparent than essential. That all these sandstones are composed of the broken and triturated ingredients of older crystalline, generally granitic compounds, is evident upon inspection. Their most abundant ingredient, sand, is plainly in the state of minute pebbles, and the size of these grains is sometimes so very small, that their coherent mass assumes almost a crystalline aspect, as, for example, in the calliard stones. On the other hand, in mill-

101 Millstone Grit. Carboniferous System, Yorkshire.

stone grit they are of all sizes under an egg, though pieces of greater size than this are sometimes seen. These are evidently quartz pebbles of different kinds, corresponding to the quartz of veins and of

granites. Rose quartz has also been observed. The next abundant ingredient is felspar, which is probably present in all these sandstones. In the millstone grit this mineral occurs in *rounded pebbles*, whose *internal structure is perfectly crystalline*, like the large rhomboidal crystals in the porphyritic granites. Hence we learn clearly the history of such a sandstone deposit. The materials were derived from crystallized rocks, and were subsequently more or less rolled about and deposited in water. Mica, the third ingredient of granitic rocks, is less abundant in millstone grit, except in certain layers where it is occasionally very plentiful. It is usually of a pale silvery colour, and is in very thin fragmentary scales. The decomposition of the felspar leaves a white, soft, unctuous substance, analogous to the kaolin of decomposed granite, and this forms a feeble cement for the grains of sand and mica. Occasionally in millstone grit, as in the other sandstones of the carboniferous system, we find oxidulous iron, and some other mineral substances not easily recognized, and in Lancashire, frequently fragments of shale, coal, &c. Everything, therefore, concurs to prove the mechanical watery origin of millstone grit, and by consequence of all the other sandstones associated with it, the differences between them being only of degree. In the same manner nearly a gradual series of changes assimilates sandstone and shale, and it is sufficiently proved that the only really chemical aqueous deposit of this whole system is the limestone.

The millstone grit of the southern coal fields is usually a much harder and more compact and cherty rock than the coarse pebbly strata which bear this name in the north of England. Finally, we must repeat the remark previously made, that this series is limited in extent, not being of much importance or really characteristic of a certain period except between the Trent and the Tyne. Through the remainder of Northumberland it is less remarkable than several other equally coarse grit rocks, called crag grits in Mr. Smith's map of Northumberland, which lie in the limestone series, considerably below the upper limestone belt. Excellent building stone is furnished by this rock in Yorkshire, Lancashire, and Derbyshire, and by its representative, the "Farewell Rock" of Dean Forest and South Wales, which have the valuable property of standing great heat, and are therefore employed in certain parts of the iron furnaces.

The Coal Formation (*or Coal Measures*)

consists of alternating strata of sandstone, shale, and coal, with courses of nodular ironstone, layers of bivalve shells, and, in a certain part, argillo-calcareous balls and nodules generally enclosing goniatites, pectens, &c.

None of these strata differ individually in any essential points from

the analogous deposits in the millstone grit, or limestone series beneath; their characteristic features are derived from their combination. It is, indeed, generally true, that the sandstones of the coal measures are softer and more argillaceous than those of the series below, that the coal shales are less indurated and less fissile than the "plates" of the limestone group, and the coal generally of better quality. But it is by the *greater abundance* of the coal seams, and by the *absence* of limestone beds that the upper part of the carboniferous system is to be distinguished from the lower. It is, therefore, perfectly conceivable, that cases may occur when the lower or calcareo-carboniferous group may, by the attenuation of its limestones and the thickening of its coals, become so similar to the upper group or true coal measures, that their relative ages can be only determined by collateral evidence. This extreme case has, indeed, hardly yet been observed in any of the known coal districts of the New or Old World, but the approaches to it in Northumberland and Scotland are sufficient to show that the coal measures have no other real difference from the lower parts of the carboniferous system, than the *total* absence of the oceanic deposit of limestone. In many coal fields the reason of this difference is easily determined by the abundance of fresh water shells, beds of shale, and of ironstone, alternating with the coal.

We have seen with what certainty the range of the mountain limestone can be followed through Great Britain, and its detached portions referred to their true place in the series of its beds, and thus geological parallels be established between the Mendip Hills, Derbyshire, Yorkshire, and Northumberland. The coal measures of Great Britain cover quite as large a surface, and are, perhaps, quite as well identified in mass; but the details of the several coal fields are too discordant to permit many of these parallels to be drawn, without which the method of variation by which one such coal field becomes different from another cannot be determined. This is so entirely well known, that often in the same coal field the differences are so considerable as to render it difficult to identify the beds of the two extremes. It must be owned, however, that this is partly owing to the confusion of nomenclature amongst the workmen, though principally to the sudden changes of chemical quality to which the coal seams are liable.

The extent of the coal fields of England and Wales may be seen upon Mr. Smith's and Mr. Greenough's Geological Maps; those of Scotland also are sketched upon Mr. Smith's Map; Mr. Griffith's Surveys and Mr. Weaver's observations have contributed much information on the coal measures of Ireland, and many valuable notices in the "Annales des Mines, Annales des Sciences Naturelles," &c., make us acquainted with the same series in France. For the

Netherlands the same journals and the Memoirs of Omalius d'Halloy, and for the German and Transylvanian coal fields the works of Villefosse, Freisleben, Hoffman, Sternberg, and others may be consulted. Mr. Conybeare has given a general view of these foreign coal tracts in the Geology of England and Wales.

English Coal Fields.—We shall consider the characters of the principal English coal fields in the following order:—

1. The great northern coal fields of Northumberland and Durham, Yorkshire, Derbyshire, and Nottinghamshire, and the scarcely separated fields of Cumberland, Lancashire, and Cheshire.
2. The south-western coal fields of South Wales, Dean Forest, Somersetshire, and Kingswood.
3. The coal fields of North Wales and Shropshire.
4. The central English coal fields.

That the great northern coal fields of Northumberland and Durham, and of Yorkshire and Derbyshire, were formed under very similar circumstances, probably connected towards the borders, and united in the deeper parts of the deposit, will appear from the following comparisons. The northern and southern portions of this great tract, though now separated sixty miles, agree in being formed within a belt of coarse pebbly sandstones (millstone grit), associated with thin coals, which overlie the mountain limestone, and in being covered *unconformedly* by the magnesian limestone. Coals of like quality are worked in these coal fields in the same parts of the series, bituminous coals of excellent quality in the lower part, quick burning coals in the upper part. Ironstone courses are most plentiful in the middle and lower part, where also lie the "mussel bands," of which regular layers have been some time known in the coal field of Yorkshire and Derbyshire, and are not without representation in that of Newcastle. This latter analogy is very remarkable, and the occurrence of these mussel bands is almost a peculiar character of the great northern coal fields.

A comparison of the details of these coal fields would afford an excellent test of the points of analogy, and the extent of variation which may be expected to occur in neighbouring carboniferous deposits.

The broadest part of the whole tract is between Halifax and Ferrybridge, or rather Went Bridge, in Yorkshire, where the dip is moderate and regularly to the south-east, the stratification not subject to more than usual disturbance, and the greater part of the coal seams are worked to supply the wide-spreading industry of the West Riding. The whole coal system of the country is thus unfolded, all its products are employed, and the ranges of most of the beds perfectly known. In addition it happens fortunately, that not only the millstone grit is remarkably distinct, and the series immediately

above it, the lowest part of "the coal field," unusually developed, and rich in organic remains, both animal and vegetable, but the uppermost part of the system beneath the magnesian limestone is also fully exhibited. There is therefore on all accounts one of the most complete coal fields in the island, and the fittest to serve as a type of comparison for the others.

Yorkshire Coal Field.—The following mode of classification of the Yorkshire coal seams will be found very natural and convenient, for the several groups of coals here assumed have certain collective characters derived from this combination, and occupy distinguishable ranges of mostly argillaceous country between lines of sandstone hills.

Magnesian limestone unconformedly covers the coal seams.

Upper coals............	Shales and Badsworth coal.
	Ackworth rock.
	Wragby and Sharlston coals.

Red rock of Woolley, Hooton—Roberts, &c.

Middle coals............	Furnace coals.	Barnsley thick coal.
	Intermediate coals.	Rock of Horbury. Middle coals.
	Ironstone coals.	Silkstone and Flockton beds. Low Moor coals.

Flagstone rock of Woodhouse, Bradford, Elland, Peniston, &c.

Lower coals............	Shales and ganister stone.
	Coals.
	Shales and ganister stone.
	Coals.
	Shales, &c.

Millstone grit lies below the "coal series."

Lower or Ganister Coal Series.—The lowest portion of the Yorkshire coal strata resting upon the millstone grit produces comparatively but a small quantity of coal, and this not in general of a good quality. But no part of the coal field is more curious in its geological relations, or more worthy of close study by those who desire to penetrate into the history of the production of coal. We may define this lowest coal series very simply by saying, that it is included between the millstone grit beneath and the flagstone rock above, having a thickness of about 120 or 150 yards, and enclosing near the bottom two thin seams of coal, one or both of them workable, and several other layers scattered through its mass too thin to be worth working.

The most regular and continuous of all these coal seams, reaches in a few places the thickness of twenty-seven or thirty inches, but is

generally only about sixteen inches, and is worked at Yeadon, Rawdon, and Horsforth, near Leeds; at Baildon and Heaton, near Bradford; at Catharine Slack and Swan Banks, near Halifax; at Bull Houses, near Penistone; and at several points west of Sheffield. It would have been impossible to have traced so thin a seam of coal along so extensive a range without some peculiar facilities, some points of reference more distinct than the varying quality of the coal, and the still more irregular fluctuations of the sandstones and shales. This coal seam is covered by a "roof" unlike that of any other coal bed above the mountain limestone on the eastern side of the island; for instead of containing only the remains of plants or fresh water shells, it is filled with a considerable diversity of *marine shells* belonging to the genera pecten and goniatites, and in one locality specimens of orthoceras. Posidonia and scaly fishes have been obtained from certain nodular concretions, called "baum pots," lying in it. The uniform occurrence of these pectens and ammonites, through so wide a range, over one particular thin bed of coal, and in no other part of the coal strata, is one of the most curious phenomena yet observed concerning the distribution of organic remains, and will undoubtedly be found of the highest importance in all inferences concerning the circumstances which attended the production of coal.

In this part of the coal system we may observe, besides the very remarkable layer of marine shells, several occurrences of a peculiarly hard siliceous sandstone, called galliard, ganister, seatstone, &c., which, in fact, is the same thing as the crowstone of the mountain limestone series in Swaledale. This stone in some cases forms the floor or sill of the coal, a circumstance never observed in the upper coal strata of Yorkshire, which, indeed, always rest on a peculiar fine clay or seat earth, full of stigmaria roots, but in these upper strata galliard never occurs in its true character; Hence this whole group of strata of group may be appropriately termed the ganister coal series.

The goniatites, nautili, and pectens which lie above one of the seams of coal, and still more the orthocerata which sometimes accompany them, are remarkably analogous, and, indeed, in part identical with fossils of the mountain limestone. The galliard is likewise to be compared with similar stones in the mountain limestone series, and therefore the ganister coal series might be with much propriety associated with the upper mountain limestone series of the Pennine chain, or with the millstone grit series of Derbyshire, and thus the flagstone would appear to be the lower limit of the true coal measures. But an examination of the neighbourhood of Halifax has shown another order of phenomena and another set of shells, which connect this same series with the upper or true coal measures.

In the upper coal series of Northumberland, Derbyshire, and Yorkshire, are several layers of bivalve shells, commonly referred to the genus unio, from which the fresh water origin of these coal deposits has been inferred. In the midst of this series of ganister coals two layers of these shells occur, one of them about the middle of the series, considerably *above the pecten coal*, the other near the bottom, and considerably *below that coal.*

No shells of this kind have ever been met with in the mountain limestone group, which there is every reason to consider as of decidedly marine origin; not one of all the zoophytic, testaceous, or crustaceous reliquiæ of this limestone has ever been found in the upper coal series. This opposition of zoological characters would appear to be fully explained if the coal deposits were admitted to have been accumulated in fresh water, or at the mouth of an estuary. And this opinion is perhaps generally adopted.

We find then in the lowest coal series, which is placed on the line of transition between the marine and fresh water deposits, zoological and mineralogical characters common to both. Examined in detail we find these characters not mixed, but alternating in such a manner as if there had been one periodical return of the marine element into its ancient receptacle, after that had been for some time occupied by fresh water and its few inhabitants. The effects of this irruption having as it were worn out, the zoological characters of fresh water deposits are again manifested at intervals, in the upper system of coal beds, till this series is finally ended, and marine exuviæ reappear in the magnesian limestone.

If, from whatever cause, we could witness the effects of a general irruption of sea water into a modern lake of great extent and considerable depth, it is probable that the resulting phenomenon would be perfectly analogous in kind to those described above. But this irruption of the ancient ocean into the coal basin of Yorkshire, was probably not produced by any violent convulsion in that basin, (for there is no unconformity between the supposed fresh water and supposed marine deposits,) but by some disturbing causes of a more general character, or else originating at a distance. Similar occurrences of marine shells in the same part of this coal series have been noticed in Lancashire; they are in fact the same phenomena, and have been repeated there more than once in the lower coal measures or " mountain mine" group. It is easy to conceive that in the course of a gradual depression of the whole tract, by which successive beds of vegetables were accumulated, particular combinations might arise, which should admit for a time, and then again exclude the sea water with its characteristic form of life. The periodical revolution in the nature of the waters which operated the deposition of the lowest coal strata in Yorkshire, bears so remarkable an analogy to some of the

phenomena of the marino-lacustrine tertiary deposits, that the same principles will probably serve as a basis for the explanation of both cases.

In both cases we have a *decidedly marine* deposit below, and a *decidedly fresh water* deposit above; the intermediate ground is not exactly neutral, but sometimes shows gradations from one to the other, and sometimes periodical alternations, accompanied, however, by so entire a parallelism of strata, that in seeking for the cause of these changes, we are compelled to have recourse to general subterranean depression, rather than to the blocking up of the outlet of an estuary, or to irruptions of the sea, arising from violent subterranean disturbances in a different quarter.

Flagstone Rock.—The lower coal series of Yorkshire is terminated above by a thick deposit of sandstone, which is never so coarse as the millstone grit, and generally appears to be more argillaceous. Its degree of consolidation varies according to localities and circumstances of drainage, but there is hardly a single point in its whole range, from the vicinity of Leeds to beyond Sheffield, where the title of flagstone rock is not eminently applicable to it. Along this whole range, by the valley of the Aire to Bradford, over the hills to Halifax and Elland on the Calder, and by Huddersfield and Peniston to Sheffield, it is the grand repository from which the immense demand for Yorkshire flagstone, both within the county and for all the Eastern and Southern coasts, is supplied. In particular situations, especially near the surface, it is often so thinly laminated as to produce good roofing slate, while the deeper parts of the quarries produce capital building stone. This diversity of qualities is consistent with great simplicity in structure. It is a finely laminated stone, having its beds in general very parallel, and thus, according as the whole mass of a bed is employed, or as it is split into portions or resolved into its component plates by the action of natural causes, wallstone, flagstone, and slate result. The micaceous surfaces of every common flagstone immediately disclose to us the cause of its natural partings; and further examination shows the whole thickness to be divided by other layers of mica into a number of parallel plates, which sometimes separate by the mere influence of the air, but generally, after being once dried, cohere together with considerable force. In this case it is difficult to say what technical use should be made of the term *strata*, which may with equal verbal accuracy be applied to the micaceous laminæ, or the plates of slate or flagstone, to the beds of the rock singly, or the whole united mass of sandstone layers. In Mr. Smith's nomenclature the whole flagstone, rock is one stratum. However this may be determined, there can be no doubt that even the least and thinnest of the micaceous layers owes its origin to a particular operation of water, and required the intervention of a

certain interval of time, to permit the separation of the grains of sand and the scales of mica.

It has been said above that the micaceous laminæ, plates of flagstone and beds of the rock, were all parallel. This is usually and very exactly the case, but in certain places while the beds and flagstones, which are only lesser beds, are parallel to one another, the micaceous layers which make up the mass of the beds, form considerable angles with the plane of their surfaces.

Thus in fig. 5, p. 29, the upper part of the diagram shows all the partings parallel; and this is the ordinary case of the flagstone rock, but in the lower part of the diagram the micaceous laminæ are inclined to the other surfaces of parting.

Such flagstones have generally a rough or ragged surface, and are much liable to scale off in irregular "shells," which disfigure the beauty of the stone. This oblique lamination of the mica strongly reminds us of the "false bedding" of millstone grit, and of the shelly beds of oolite, which probably were formed in the currents of slightly agitated water.

The surface of the rougher flagstone beds is also liable to other peculiarities, as waves or undulations, like the ripple marks on a sandy shore, little hard knobs on one face corresponding to depressions on another, and sometimes a vermicular marking, which sometimes resembles the arrangement which semifluid matter assumes on smooth surfaces of stone, when these, after having been laid together, are forcibly pulled asunder, but in other cases indicates the trail, or preserves the form of free annelida.

The micaceous layers are not unfrequently coloured with a mixture of carbonaceous particles.

Vegetable remains lie in this rock in many places, and in considerable plenty. Equisetiform plants in particular are abundant in it about Leeds, accompanied by trihedral fruits. Lepidodendra, sigillaria, &c. occur in it less plentifully.

In general, what is said of the accidents of structure of the flagstone rock of the Yorkshire coal fields applies to the laminated sandstone rocks of the mountain limestone, and even to the analogous but more recent layers in the oolitic coal system on the coast of Yorkshire.

Middle Coal Series.—This is the most valuable part of the Yorkshire coal field, and includes as many as ten workable seams of coal, of various quality, with several layers of ironstone bands, one of them full of fresh water shells. The flagstone rocks define the series below, and the coarse, often iron-stained sandstones of Newmiller Dam, Woolley Edge, and Rawmarsh form its upper boundary.

It may be convenient to divide this great group into three portions, thus:—

	Red rock of Woolley Edge.
	Furnace coals of Barnsley, &c., including the eight or ten feet seam.
	Rock of Horbury and Wentworth House.
Ironstone coals......	Swift burning coals of Middleton, Dewsbury, &c., with bands of "mussels."
	Bituminous coals of Silkstone and Low Moor.
	Flagstone rocks beneath.

Upper Coal Series.—Upon the coarse rocks of Woolley Edge lies the upper series of coal measures in Yorkshire, which exhibits alternations of sandstones and shales very much like those of the middle and lower groups, but without the layers of mussels, and generally without the presence of productive ironstone bands. The reliquiæ of plants are more rare in these strata, and the coal is of inferior quality, more earthy and less bituminous. Two considerable seams of coal near the bottom, worked at Wragby, Sharleston, &c., and one or two thinner seams nearer the top of this series, appear to be the last of the formation, and are unconformably covered, as are all the others in their turn, by the magnesian limestone, against which deposit the line of separation is hard and distinct.

There are no trap dikes in this coal field, but many faults, passing nearly E.N.E. and W.N.W., and others nearly N.N.W. and S.S.E. The "cleat" of this coal is from N.W. or N.N.W. to S.E. or S.S.E. The cross cleat is sometimes hardly traceable.

The small coal field of Ingleton and Black Burton in Lonsdale is thrown down on the south side of the great Craven fault.

Comparisons with other Coal Fields.—We are now in a condition to institute a comparison between the results of observation on the strata of the Yorkshire coal fields, and those which had been drawn from similar researches on the other coal districts of Britain and the continent. For this purpose it will be of little use to take into account the number or thickness, or chemical quality of the beds of coal, since these characters, however important locally, are too variable to guide us across even the whole extent of a single coal basin, and vanish altogether upon distant points. We must, therefore, restrict ourselves to the most general divisions of the carboniferous series, and compare the coal fields with reference to the strata which separate the coal from the mountain limestone beneath, the occurrence of bands of ironstone and mussel-shells, the nature of the rocks and shales, and the distribution of organic remains.

Notwithstanding the great interval in the superficial range of the coal strata between Aberford and Cockfield Fell, the series in the Durham and Newcastle coal fields is very analogous to that of Yorkshire.

But hitherto, no layer of marine shells has been noticed in the lower part of the Newcastle coal fields, and, therefore, the inference

of alternate inundations of the sea and fresh water cannot be applied to this coal field, though the general conclusion of marine deposits below, and fresh water deposits above, remains unimpaired.

The total thickness of the coal measures is about 1,600 feet, the number of distinct layers or beds as usually noted by the miners about 600, the total thickness of the beds of coal rarely exceeds—does not on an average equal—sixty feet. No bed of coal is of greater thickness, even for a short distance, than six or seven feet—several are so thin as to be of no value at present—the total thickness of "workable coal," supposing all the beds to be found in a given tract, is not to be estimated at above twenty or thirty feet. The most part of the coal in this great district is of the coking quality, but in this respect there is much variation. The best coke, for locomotive engines, is now made from the lower coals in the Auckland district of Durham, and Shotley Bridge district of Northumberland. The best "steam coal" is obtained from the north side of the Tyne and the Blyth district. The best "house coal" still comes from the remains of the "High Main" on the Tyne, and from the "Hutton Seam" on the Wear; but the collieries north of the Tees have acquired a high reputation.

As a general view of the groups of strata the following summaries may suffice:—*

	Feet.
Upper group of coal measures, including chiefly thin seams of small value (eight or more) in a vast mass of sandstones and shales, with some ironstone. At the base is a mussel band; we estimate this at	900

	(ON THE TYNE.)			(ON THE WEAR AND TYNE.)
Middle Group.	HIGH MAIN coal.... often	6	feet.	Unknown.
	Strata and thin coals......	60		
	Metal coal..................	1	6	Five quarter coal .... 3 9 to 6 9
	Strata and thin coals.......	30		
	Stone coal..................	3		
	Strata.......................	83		
	Yard coal	3		
	Strata.......................	90		Main coal.................. 5 6 to 6 0
	BENSHAM SEAM............	3		
	Strata with several variable beds and some layers of mussels......	150		Maudlin seam.............. 4 6 to 6 0
	LOW MAIN COAL...........	6		Low main or Hutton seam 4 6 to 6 6
Strata.............................		200		
HERVEY'S SEAM.................		3		Beaumont seam........... 3 0 to 6 0
Strata		300		
BROCKWELL SEAM		3		Brockwell seam........... 3 0 to 6 0
Strata above millstone grit......		200		

The field is traversed by great dislocations, the most remarkable being the ninety fathom dike which throws down to the north, and

* See Forster's Mining Section. Winch. in Trans. of Nat. Hist. Soc. of Newcastle, and Buddle in the same, &c.

runs down the valley of the Tyne, through the collieries north of Newcastle, to the sea cliffs north of Tynemouth. Many dikes of greenstone also divide the coal measures, producing upon the coal the effect of charring and partial prismatization, but they are unaccompanied by dislocation, except, and that partially, the great dike in the south of the county of Durham, called the Cockfield Fell dike, which crosses the district from W.N.W. to S.S.E., and traverses the coal, red sandstone, lias and oolites. The "cleat" or principal system of natural nearly vertical fissures runs through the whole district in a direction from N.W. to S.S.E. There is an obscure cross cleat. By the sides of a remarkable vertical trap dike at Coley Hill, the shales are greatly altered; so that their original stratification becomes less and less traceable as we approach the dike, and another structure consisting of vertical fissures is substituted; the fissures growing more and more numerous and closer together the nearer we approach to the dike, so as to constitute a real cleavage. (Observation, 1834.)

The Lancashire and Cheshire coal fields are certainly portions of this great northern system, separated in consequence of the subsequent uplifting of the mountain range of the Pennine Alps. The same *ganister* and flagstone occurs near Stayley Bridge, resting in the same order of succession upon the same millstone grits as in Yorkshire, and though the broken condition of the coal fields on the West of the summit ridge scarcely allows of the same accurate delineation of the courses of the coal beds, enough is already known to justify the reunion of the coal deposits on both sides of the Pennine Alps.

The coal field of South Lancashire occupies a large area extending —if we include the millstone grit—from Macclesfield to Colne, forty-six miles, and from Torbock near Liverpool to Todmorden, about forty miles—excluding the millstone grit, its area is about 250 square miles.* The thickness of the whole series varies in a line of section from Manchester to Hollins Brook, the strata measure (including millstone grit) 6,000 feet; and include seventy-five beds of coal, exceeding one foot in thickness, and forming altogether 150 feet of coal. In a line through Worsley, Bury, and Burnley, to the limestone shales of Pendle Hill, we have thirty-six seams of coal, ten of them not exceeding one foot in thickness, making in all ninety-three feet of coal.

The series is divisible into three parts; above the millstone grit—

Upper Part—containing a bed of limestone, at Ardwick, near Manchester, with remains of Palæonisci and other fishes, spirorbes, &c.

Middle Part—containing the greater part of the thick and valuable seams, especially the cannel coal of Wigan, &c.

* Heywood in Reports of Brit. Association, 1837; Williamson in the same vol.; Peace in the same vol.; and Binney in the vol. for 1842.

Lower Part—corresponding to the ganister series of Yorkshire, with marine shells, &c., as pecten, goniatites, posidonia, &c.

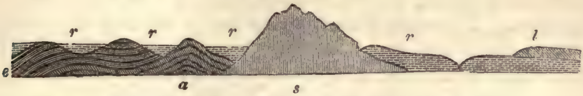
Enormous faults divide the Lancashire coal field: one stated to cause a dislocation to the extent of 1,000 yards, is called the "red rock fault," north of Pendleton near Manchester. Near Wigan many faults range nearly N.N.W. and S.S.E., causing up throws and down throws of 171, 220, 340, 440, and 540 yards. The "cleat" or cleavage runs invariably N.W. and S.E. There is a bed of Unionidæ above the flagstone, which corresponds with the rock so named in Yorkshire; and shells of this group, microconchi, and cyprides, are scattered through many of the shales. In West Lancashire the thickness of workable coal is about eighty feet, and the total thickness of the strata 6,000 feet or more. At least 6,000,000 tons of coal are raised annually from this rich district.

The Great Northern Coal Fields.—The characters of the Yorkshire coal fields are recognized in their continuation southward through Derbyshire and Nottinghamshire. The same ranges of millstone grit and shales lie beneath, similar rocks of hard ganister lie in the lower part, with a similar belt of useful flagstone. The lower part of the series contains the most bituminous coals, in the middle are the best and the most abundant courses of ironstone, some of which contain fresh water shells, and the upper parts yield similar swift-burning coals. The thickest coal in the district, called the 'top hard,' is the same bed as that called the thick or ten-foot coal in Yorkshire—in point of position high in the series, and not much removed from the parallel of the "high main" of the Tyne. One of the best coals is that bed, low in the series, called the black shale coal, which is the same as the equally approved Silkstone coal of Yorkshire. The Derbyshire and Nottinghamshire coals are classed, as to *structure*, in two varieties: as "hard" coal, in which the divisional structures are chiefly derived from the planes of stratification, crossed by one set of "cleat," or natural joints (called "slines," "backs," &c.), so that large prismatic solid masses result; "soft" coal, where the cleat fissures are numerous and broken by cross cleat. In respect of *quality*, some of the coal is of a "*crozling*" or caking nature, easily fusible, and changing its figure by "coking;" the rest (and this is specially the case with the "hard" variety) makes both good furnace coal and excellent coke, which, however, is hardly melted at all, and the masses are not changed in figure by the process.

There is no trap dike in the Derbyshire coal field. The strata are affected by anticlinals and faults, but on the whole lie with much regularity, and yield largely. About twenty beds and sixty feet may be regarded as workable, though not all in one district, some being good in the north and others in the south. On an average, thirty feet may be computed as attainable almost everywhere on the eastern

side of Derbyshire, the field extending there *far beyond* the edge of the magnesian limestone, and promising future supplies.

Central Coal Fields.—The double coal field which surrounds Ashby de la Zouch is formed in two parallel bands, partially separated by an anticlinal, and the northern of these bands is based on mountain limestone, which, like some portions of that of Derbyshire, contains abundance of magnesia; there is, however, no particular correspondence to be remarked in other respects; some trace of millstone grit has been recognized, but no flagstone nor ganister measures. Amongst the seams of coal is one of the variety called cannel, and another formed by the concurrence of more than one band, from seventeen to twenty-one feet in thickness.



102 *s* Silurian and Cambrian rocks of Charnwood. *a* Carboniferous limestone. *e* Coal measures. *r* New Red sandstone. *l* Lias.

The strata range from N.W. to S.E., parallel to and on the western side of the axis of Cambrian or Silurian rocks of Charnwood Forest. The mountain limestone is only seen to come out beneath the coal on the northern side, and then is much interrupted and greatly disturbed in position. At Swannington, Mr. G. Stevenson sunk through a great mass of trap to a valuable bed of coal. The quality of the coal in the Ashby district is for the most part like the "hard" coal of Derbyshire.

The strata of the Warwickshire coal field are based upon a compact cherty sandstone, called by Mr. Conybeare "millstone grit," but really a Silurian or Cambrian rock. No limestone appears round the escarpment of this narrow coal tract. The seams of coal are liable to great changes of thickness, in consequence of the occasional attenuation of the interposed strata of shales. They are in general much inclined to the horizon, and dip to the W.S.W.—the dip being greatest on the eastern edge (45°), where the appearances indicate an anticlinal or great fault.

The range of this coal field—so far as it appears from below the new red and Permian sandstone—is from a point east of Tamworth to a point east of Coventry, about twenty miles from N.W. to S.E., parallel to the Ashby coal tracts. The strata are most productive of coal near the southern extremity, where, at Bedworth, by the coming together of two seams worked separately at Griff, the five yard seam is worked.

Between Nuneaton and Coventry, and near Griffe Hollow, two greenstone beds appear to interlaminate the coal strata (thirty feet or more in thickness). No trap dikes occur in this coal field, and no metamorphosis accompanies the greenstone beds. (Conyb. and Phillips's Geo. of Engl. and Wales, i. 446.) The analogy of these facts to those in the Ashby de la Zouch and Leicestershire district is obvious—the separation between them being not original, but due to anticlinal movement.

South Staffordshire Coal Field.—The coal field of Dudley, Bilston, and Cannock Chase has a length of twenty miles from north to south, and a breadth nowhere exceeding seven miles visible at the surface. It agrees in part with that of Coalbrook Dale, but differs from all the others by the character of the subjacent limestone, for this is proved to belong to the Silurian system—to be, in fact, Wenlock limestone. The coal measures are really but not obviously unconformed to the limestone; their dips correspond in direction if not in degree. The limestone is uplifted into a saddle-shaped or anticlinal ridge; the coal strata rest upon its slopes, and are covered by the new red sandstone formation.

There is no millstone grit, nor any flagstone, and (as usually among the central coal basins) the strata are mostly argillaceous. Ironstone courses occur in several parts of the series, but the only valuable ones are near the bottom. The seams of coal are numerous, but only the lower ones are workable. They are of various thicknesses, from four to six and eight feet in the northern parts, and ten yards, or even fifteen yards, in the southern part.

It is not, however, to be supposed that this enormously thick seam is a single bed of coal; it is in fact composed of thirteen different beds locally accumulated together, with certain partings, which in other places swell out into considerable thicknesses of shale. Thus the upper part of the ten-yard coal separates from the rest of the beds, and under the title of the "flying reed," becomes a totally distinct bed in the northern part of the coal tract.

As before observed, the coal strata rest on Silurian rocks, sometimes on their planes, sometimes against their cliffs; these rise in picturesque anticlinal bosses on a line running N.W. from Dudley, and show themselves in a larger and lower tract east of Walsall. There is also a narrow tract of Caradoc sandstone running N.N.W. in the Lickey Hills. This small tract has a point of trap at its southern end; there are six other points and one large mass, called the Rowley Hills, south-west, south, and south-east of Dudley; and two other small masses west of Walsall. The tract is much disturbed by flexures locally connected with the Silurian bosses near Dudley, and a small greenstone mass between Dudley and Stourbridge. The coal and limestone are equally affected by these flexures; the

coal and subjacent Silurians near Walsall are displaced by the same faults; in other situations the basaltic masses are affected by these faults; and finally, some are found also to divide the lower new red (Permian) and the new red sandstone (Mesozoic). Mr. Jukes, to whose memoir* we are indebted for the information, classes the coal strata in three divisions, by the well traced band of thick coal; the total thickness of *coal* near Dudley being about fifty-seven feet, and between Bilston and Wolverhampton upwards of seventy feet.

Beds above the Thick Coal.	Feet thickness.	
Strata above the sulphur coal	to	This thickness is incomplete; in the vicinity of Halesowen probably the whole thickness above the thick coal is 1000 feet.
Sulphur coal	0 to 1½	
Strata	140	
Little or two-foot coal	1 to 2	
Strata	2 to 48	
Brooch coal	2 to 6	
Strata containing Brooch ironstone	7 to 20	
Herring coal	0 to 1½	
Pins and Pennyearth ironstone	6 to 30	
Strata containing thick coal rock	38 to 157	
Broad earth and catch earth and batt	6 to 14	

The thick coal is formed of eight, ten, or thirteen distinguishable parts, the whole seam varying in thickness from three feet to thirty-nine feet five inches; it is very irregular in parts, divided by sandstones, splitting into wide-shaped offshoots, and cut into "swills" or "horse backs," which rise up from the floor.

Beds below the Thick Coal.	
Chiefly batt (argillaceous schist)	2 to 8
Gubbin ironstone measures	2 to 8
Strata	2 to 28
Heathen and rubble coals and partings	5 to 43
Strata	10 to 33
New mine ironstone †.	2 to 10
Strata containing Pennystone ironstone †	10 to 25
Sulphur coal	2 to 9
Strata	2 to 99
New mine coal	2 to 11
Strata	2 to 40
Fire clay coal	1 to 14
Strata, including Poor Robin and white ironstone	8 to 44
Bottom coal	3 to 12
Strata	5 to 30
Gubbin and balls ironstone	0 to 10
Strata, including singeing coal	40 to 85
Blue flats, silver thread, and diamond ironstone	0 to 40
Lowest measures	0 to 50

The whole series below the thick coal, however variable in its

* Records of the School of Mines, I., Part 2.

† The ironstone contains marine shells as in the Coalbrook Dale field, lingula, producta, orbicula, conularia, fish teeth, &c.

parts, measures pretty generally on an average about 320 feet (80 feet less or more), but they thicken toward the north.

Regarding the igneous rocks of the South Staffordshire field, Mr. Jukes's observations show, besides the basaltic masses against which—rising as they do through the strata—the coal measures, whether they abut or pass under it, suffer alterations due to heat, some partially interstratified masses of igneous rock, called "green rock." This occurs in sheets of considerable thickness (60 feet + 30 feet), which spread in area (Barrow Hill) as much as two miles horizontally, and have much wider ranges from Rowley Hills to the northward. From the basaltic masses wedge-like portions pass off laterally into the coal measures. All these trap rocks are of later age than the coal which they traverse and alter; but Mr. Jukes thinks they are not of more recent date than the coal measure period. In the southern part of the field, sandstones in the coal section are made up of the detritus of such igneous rocks.

North Staffordshire Coal Field.

The triangular space included between Congleton, Newcastle-under-Line, and Lane-end, is formed in synclinal and anticlinal folds, and broken by great faults. It contains a valuable series, or rather double series of coal seams, occupying altogether a thickness of several thousand feet. Its numerous collieries supply the populous district of "the Potteries." About 32 beds of coal have been determined rising eastward between Burslem, in the centre of the field, and its eastern limit near Norton church, where the lower or millstone grit series begins to appear. The section is also pretty clear in the north-westerly direction, the beds rising towards the millstone grit of Moel Cop. While traversing this district some years since, we found reason to conclude that the southern boundary was "faulted;" the beds of coal being thrown down below new red or "bunter" sandstones, apparently continuous with those near Ashbourne and Nottingham. But near Stoke, and Newcastle-under-Line, are beds of a different and less ferruginous aspect, reminding us of Permian sandstones and shales.

The detached coal works about Cheadle belong to the ganister or millstone grit series, and are continuous with a long range of such deposits near Macclesfield, Whaley Bridge, and Glossop.

Cumberland Coal Field.

This coal field, though limited in extent to a narrow crescent, from Whitehaven to near Hesket Newmarket, is very productive near the

sea coast, and is actually worked very widely under the sea at Whitehaven and Workington. It contains several seams of coal, one nine feet in thickness.

Flintshire.—The well-connected coal basin of Flintshire, in the course of which the estuary of the Dee is formed, extends from north to south somewhat more than 30 miles, from Llanassa to near Oswestry in Shropshire, forming an exterior belt coextensive with the range of the mountain limestone from the north of the Clwyd; where that limestone is partially interrupted by the mountain of Selattyn, the coal shales rest immediately on the Silurian slate of that mountain. The coal strata dip generally eastward, and form in the northern part a trough beneath the estuary of the Dee, and rise again on the eastern side of that estuary in the district called Wirral, from whence, sinking again beneath the red sandstone, along the course of the Mersey, they may possibly be prolonged to the South Lancashire coal beds, near Prescot.

This coal basin in Flintshire commences with beds of shale and sandstone, answering in position and character to the shale and millstone grit of Derbyshire. The coal is of various thickness, from three-quarters to five yards, and consists of the common, cannel, and peacock varieties. (Geology of England and Wales.)

Plain of Shrewsbury.—The broken patches of coal strata which lie on the south of the Vale of Severn, near Shrewsbury, are arranged according to the irregular positions of the Silurian and Cambrian rocks, which in the Stipperstones, Longmynd, Wenlock Edge, the Wrekin, Caer Caradoc, &c., extend themselves in a curve far to the east of the great body of the slate rocks. The true relations of the coal strata to the Silurian ranges, between whose projections they are enclosed, have been carefully examined by Murchison,* and connected with general views of the dislocations along the line of the upper slate formations. It appears that the carboniferous strata repose on the edges of the older rocks, and dip towards a common centre under the new red sandstone. At Pitchford the whole carboniferous series is represented by a bituminous breccia, of a few feet in thickness. Three thin beds of coal are, for the most part, observable, and the deposit is distinguished by an included band of limestone similar in mineral aspect to the lacustrine limestones of Central France, and containing minute spirorbes very like to those mentioned above from the upper coal series of Lancashire and the middle coal seams of Yorkshire and Northumberland.

Coalbrook Dale.—On the east side of the transition ranges of the Wrekin and Wenlock Edge lies the coal field of Coalbrook Dale, which contains at the bottom a sandstone conglomerate called the little flint, of which the lower part abounds in pebbles, and is in fact

* Silurian System, 1837.

a millstone grit. Somewhat higher is a representation of the "ganister" of Yorkshire. The ironstones, which lie in five or six layers, are balls or broad flat masses, like those in Yorkshire, &c., and contain abundance of the same vegetable impressions, and shells, belonging to the marine genera orbicula, conularia, goniatites, &c., which render an inquiry into the *distribution of the molluscous remains* very interesting.

Coalbrook Dale Coal Field.

We are indebted to Prestwich* for a complete survey of this remarkable coal field, which on the north and east is entirely bounded by faults and new red and Permian rocks. On the west it rests on a representative of the millstone grit; or on mountain limestone, or on some of the several beds of the Silurian series. On these Silurian rocks, it is really unconformed, and for the most part this unconformity is quite proved on a large scale; but, as in the Dudley field, to which this bears more than analogy, there is in many places very little difference of direction or angle of dip between the Silurian and carboniferous strata. The field is bounded on the extreme west by Caradoc sandstone and the associated traps, and on the south-east by old red and upper Ludlow; between these extremes the Oswestry, Lower Ludlow, and Wenlock series may be seen, the coal not so much abutting against them as easily reposing on them.

Trap rocks appear on the boundary, at Lilleshall, and in the midst of the field at several points north of Coalbrook Dale; these being connected below into a great mass, under the coal and mountain limestone. Farther north, a similar rock occurs underground, also below all the coal, but does not reach the surface. It also lies under the limestone of Steeraway.

Perhaps there is no coal tract known which, in so small a compass, about twelve miles long, and, at most, three and a-half miles wide, exhibits so many curvatures in the outcrops, crossed by so many continuous faults, some ranging north by east, others east-north-east; these crossed by many of shorter length, and directed west-north-west, and in several other lines.

The total thickness is supposed to be 1000 or 1100 feet, divided into 90 distinct strata. The coal varies in the total thickness from 16 feet to 55, and in the number of its beds from 7 to 22, the increase being to the north. The "cleat" or system of joints runs from west-north-west to east-south-east. The coal is, for the most part, of the variety called slate coal in Scotland, hard coal in Derbyshire. Cannel coal is rare, sulphureous coal (pyritous) very common. Petroleum abounds in the central and upper part of the field. The

* Trans. of the Geol. Soc., vol. v.

coal beds are mostly thin; the ten uppermost are too sulphureous for other uses than lime-burning, and are called stinkers; twelve beds of good coal, in all twenty-five feet thick, the thickest being five feet, succeed, and the lowest bed of the whole formation, eight inches thick, is sulphureous. Ironstones abound, and, like the coal seams, increase in number and thickness towards the north, from 1 band to 8 bands, and from a thickness (including the shales worked with them) of 3 feet to 72 feet. The Pennystone is the most productive, yielding 1 ton 4 cwt. per square yard, while the other beds, taken together, make only an addition of 1 ton 18 cwt. Their specific gravity is from 3·30 to 3·68.

The sandstones of this coal tract are usually fine-grained and micaceous, and speckled with fragments of coal; but some of them are coarse-grained, and two remarkably so. The sandstones generally contain vegetable impressions, but only in one case form the roof of the coal, which is otherwise invariably shale. Two beds of coarse sandstone, fifteen and a-half feet in thickness, are entirely penetrated by petroleum, which flows out perpetually in the *tar spring* at Coalport. This bitumen is likewise found in the basses or indurated slate clays. These details are chiefly derived from observations at Madely colliery, where a pit, sunk to the depth of 729 feet, passes through all the strata, eighty-six in number, which constitute the coal formation.

The distribution of the organic remains in this coal field has been fully investigated by Prestwich. If we begin our inquiry at the south end of the field, we find in this *diminished* section the usual marks of land and fresh water or estuary life, stigmaria, sigillaria, calamites, microconchi and cyprides, and no positively marine or at least pelagian form. But as we go northward and observe the ironstones come into the section successively, marine life represented by crinoidea, brachiopoda, (producta, orbicula, spirifera,) gasteropoda, heteropoda, (bellerophon,) cephalopoda, (nautilus, goniatites,) and trilobites, becomes conspicuous and abundant. But alternating with these are still the characteristic plants, and the unionidæ which generally occur in estuary coal deposits. Five decided alternations of marine and fresh water life, and two doubtful ones are placed on record by the able and diligent author we have pleasure in quoting. The most remarkable of these marine bands is the Pennystone ironstone in the lower part of the section, (perhaps comparable to the new mine, a marine layer in the Dudley field,) and next to it the Chance Pennystone, which is in the upper part.

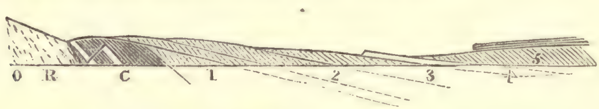
Clee Hills, &c.—The divided coal basin of the Clee Hills is elevated upon the Silurian ranges and old red sandstone which slopes eastward from Corvedale, and contains several seams of coal and layers of iron-

stone, much confused in their arrangement by interpositions of basaltic dikes and overlying masses, and resting below on a hard conglomerate sandstone. This interesting country has been minutely examined by Murchison. On three sides of the Brown Clee Hill, the coal strata rest on old red sandstone, which to the west is a coarse conglomerate; but on the fourth or south-eastern side, there is interposed between the old red and the lower coal grits, a thin zone of mountain limestone.

Trap rocks confuse the arrangement of the coal strata in the whole space between Corvedale and the Severn, including the coal field of Billingsley and Bewdley, which has also attracted the labours of the same geologist.

This district is geographically connected, though slightly, with the Coalbrook Dale field. The beds of coal are thickest in the Clee Hill colleries; at Knowlsbury the great coal is seven feet thick. There are singular occurrences of coal in the Abberley Hills to the South of the Bewdley field, both on the worn surface of the old red and Silurian rocks, and on the line of a fault, between the old and new red rocks, and in contact with syenite.

Farther south is the little coal field of Newent, placed between the new and old red sandstone, and continued by still smaller, narrower, and interrupted patches, between the new and old red northward toward the Malvern Hills. Thin coals of no great value occur in these situations, and have been explored at Bowlsden near Newent, beneath new red sandstone, indications perhaps to be trusted, of much greater deposits farther to the eastward.



103 Section near Newent.

O R Old Red. C Coal measures of Bowlsden 1, 2, 3, 4, 5, Strata of the New Red series.

Forest of Dean.—The coal strata of this entirely insulated coal field rest generally upon a coarse sandstone like millstone grit, which in like manner rests upon mountain limestone. This rock contains a layer of oxide of iron, in such plenty as to feed the iron furnaces. The coal seams, twenty-seven in number according to Mushet, contain about thirty-seven feet in thickness of clear coal, which is mostly soft and swift-burning, but in the lower seams partakes more of a coking quality. The ironstone nodules which lie in the shales are of little importance; the sandstones are mostly in the lower part of the section.

The total thickness of the coal deposits is estimated by Mushet at

500 fathoms; which may all be passed through at the centre of the district, that being also the point to which the strata dip from all sides. De la Beche* gives the total thickness thus:—

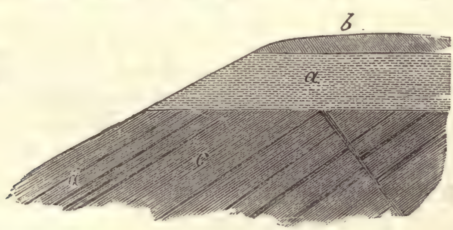
Upper shales and sandstones	1,255 feet.
Middle sandstones, &c.	1,055 "
Lower series (milllstone grit)	455 "
	2,765 feet.

In this series as in so many others the upper parts are poor in coal. Admitting 160 distinctly measured strata of very unequal thickness, we pass through fifty-six before arriving at the smith's coal, two feet six inches. In general terms we may reckon in the upper series—

Upper Series,	Above smith's coal,	970 feet,	yielding 9 beds of coal, none exceeding 14 inches.
	From that coal to the lower churchway,	286 "	including 10 beds, 7 of which exceed 14 inches.
Middle Series,	Pennant grits, &c.,	1,065 "	including 7 beds, 6 of which exceed 14 inches.
Lower Series,	Farewell rock, &c.,	555 "	no coal.

Somerset, &c.—The broken coal deposits of South Gloucestershire and Somersetshire agree in being begirt by an irregular belt of mountain limestone and old red sandstone, and occasional patches of sandstones occupying the place of millstone grit. It is seldom, however, that the passage from coal measures to the subjacent limestones is seen at the surface, because of the nonconformity of the new red, which in this district masks more than usually the interior

104



Section of dislocated coal strata (*c*) near Bristol, under New Red (*a*) and Lias (*b*). The dislocations do not enter the overlying strata.

structure of the earth. The irregular undulations of the strata, and their concealment through extensive tracts by overlying deposits, present formidable obstacles to the attempt to trace the series of beds which constitute this coal field.

* Memoirs of Geol. Survey, vol. i.

Conybeare supposes that it may contain as many as fifty or sixty coal seams, most of them very thin, hardly any of them exceeding one yard, and, therefore, unless of good quality, in a country at some distance from more productive collieries, and aided by the improvements of modern machinery, scarcely capable of being worked to profit.

As in the South Wales coal field, shale predominates in the lower, and the Pennant grit rock in the middle part of the series: the shale beds frequently contain beautiful impressions of ferns and mussel shells.

The Somersetshire coal fields have been admirably illustrated by Dr. Buckland and the Rev. Wm. Conybeare.

More lately De la Beche has added exact measures representing, it is believed, the whole series of the strata. The total thickness seems to be not less than 6,290 feet—thus distributed:—

Upper shales and sandstones	1,800 ft.	with 10 beds of coal 18 ft. 3 in.
Middle sandstones (Pennant grit)	1,725	with 5 beds of coal 10 ft.
Lower shales	1,565	with 36 beds of coal 72 ft.
Farewell rock, &c.	1,200	
	6,290	

The thicknesses assigned to the coal are in excess, because they include partings, and in the lower shales some of the under-clay. Ironstone is not common in this field, nor are unionidæ, the concomitants, frequent. The "lower shales" of this district seem not to be represented in the Forest of Dean.

Great South Wales Coal Field.—The great coal basin of South Wales (which is, in fact, as Mr. Conybeare has shown, divided into two parallel basins by a longitudinal axis of elevation,) presents so many features in common with the detached coal tracts of Dean Forest, Kingswood, and the valleys of Somersetshire, as to serve for a general term of comparison for south Britain.

The total thickness of the coal strata is very great, for in the deepest part of the basin near Neath, the lowest strata of coal are nearly 700 fathoms below the outcrop of some of the superior strata in the more hilly parts of this district. There are (according to Mr. Martin) 23 beds of workable coal, making altogether 95 feet, 12 of them from 3 to 9 feet thick, 11 from 18 inches to 3 feet; besides numerous other beds from 6 to 18 inches thick.

Logan and De la Beche have accumulated evidence which appears to justify the admission of 11,000 or even 12,000 feet thickness from the carboniferous limestone to the highest part of the coal series about Llanelly; in other parts of the field the series is found to be on proportions only less gigantic. The most general view which can

be offered seems thus, giving to the true coal measures about 8,000 feet :—

Llanelly series, with several beds of coal..........................	1,000 feet.
Penllergare series of shales, sandstones, and beds of coal—110 beds, 26 beds of coal..	3,000 "
Central series (Townhill sandstones of Swansea—Pennant grit of the Bristol field)—62 beds, and 16 beds of coal............	3,246 "
Lower shales, coals, and ironstones, (Merthyr,)—266 beds; 34 beds of coal..	812 "
Abundance of ironstone beds and unionidæ occur.	
Farewell rock and Gower shales, above the carboniferous limestone below.	

The coal on the north-eastern side of the basin is of a coking quality, excellent for the iron manufacture; on the north-western it contains little or no bitumen, being what is called stone coal or culm ; on the south side, from Pontypool to Caermarthen Bay, it is of a bituminous or binding quality. The cause of these extreme differences in the quality of the coal is not known, and, indeed, the subject of the varying quality of a coal bed has never yet been adequately investigated. Many analogous though less striking examples are familiar to every coal-worker of sufficient observation and experience.

The numerous excavations along the northern border of the South Wales coal district, for the purposes of the iron manufacture, present us with a complete section of the middle and lower parts of the coal measures, the limestone series beneath, and the general base of old red sandstone.

The lowest part of the coal measures consists of alternations of sandstone and shale; the lowest bed (in the place of millstone grit) being a siliceous or sometimes a conglomerate sandstone. Above this series, two or three thin seams of coal occur, and these are followed by an argillaceous series, containing many thick and valuable beds of coal, and sixteen distinctly characterized layers of ironstone in thin beds and nodules. The general analogy of arrangement of the coals and ironstones to that which has been described in the northern coal fields, will be immediately obvious.

It appears that the middle part of the coal strata is characterized by the predominance of coarse sandstone with carbonaceous specks, like that called Pennant in Somersetshire, and that a considerable thickness of such rocks intervenes between the upper and lower series of coal seams. This sandstone is occasionally highly micaceous and fissile, and yields very good flagstone and even roofing slate.

There are no trap dikes in this great basin ; no considerable mass of trap enters it in any form ; though in Pembrokeshire the syenitic rocks adjoin it ; the change to anthracite which its beds undergo in proceeding westward, does not admit of explanation by the presumed

agency of heat depending on the local proximity of igneous rock. Nor is it proved or very probable that it is the effect of pressure, great as that has been in the anthracitiferous region.

Carboniferous System of Scotland.

In proceeding from the northward, we first meet the carboniferous system of the British Isles on the borders of the great synclinal hollow along which runs the valley of the Forth and Clyde. This great structural hollow, which is parallel to the chains of the Grampians and Lammermuirs, is filled in its central parts with a coal field, about one hundred miles long, from St. Andrews to near Greenock, and from Dalkeith to Ayr, and fifty miles broad, much interrupted by large trap masses rising through it, and sometimes interpolated between its strata. In general, the section shows, above the old red sandstone, a great variety of shales, and some thin limestones, containing productæ, spirifera, orthocratites, &c. At Burdie House, in the vicinity of Edinburgh and Dalkeith, the limestones yielded to Dr. Hibbert many land plants (lepidodendron, sphenopteris, &c.), and some bivalvular crustacea, besides plenty of the great fossil fishes called megalicthys and holoptychius. At Carluke, near Glasgow, very beautiful fossils of the mountain limestone type occur. In general these coal fields appear to be older than those of the central parts of England, and, at least in all the lower parts, to belong to the Berwickshire series, or submedial carboniferous groups. Detached portions occur at Sanquhar and in the Isle of Arran, and we may join to the same local system the coal of Ballycastle in Antrim.

Coal Field of Midlothian.—In the Midlothian coal field, in the counties of Edinburgh, Haddington, and Peebles, Mr. Farey, sen., in 1816, ascertained 337 principal alternations of strata between the surface in the town of Fisherrow on the banks of the Frith of Forth, (where the highest of these strata occur,) the commencement of the basaltic rocks forming the general floor and border of this important coal field. These strata lie internally in the form of a lengthened basin or trough, and consist of sandstone, shale, coal, limestone, ironstone, &c.; 66 seams of coal, counting the double seams as one; 7 limestones; 72 assemblages of stone and other sinkings; in all 5000 feet in thickness.

Mr. David Milne* has published elaborate and well arranged details regarding the eastern part of the Scottish coal field—a district of about fifteen to seventeen miles square, resting partly on trap rocks, and old red sandstone and conglomerate, and partly on Silurian and Cambrian strata. The coal series appears conformed to the old red;

* Memoir on the Midlothian and East Lothian Coal Fields, 1839.

and that is, on the Pentlands and Lammermuirs, unconformed to the older primaries. Two movements of elevation are inferred, one before the old red, a second after the deposit of the coal, both very extensive in their effects. The total thickness of the strata is 1000 to 1050 fathoms (6000 to 6300 feet). In 534 fathoms, it is known that

Sandstone occupies	286 fathoms.
Shale	188 "
Limestone	27 "
Coal	21 "
Clay	12 "

And computing the whole, we have as a probable summary:—

Sandstone	550 fathoms.
Shale	360 "
Limestone	51 "
Coal	30 "
Clay	22 "
	1,013 fathoms.

The number of the component strata is thus given:—

Sandstone strata	above	4	feet thick	47, (the thickest mass, 200 feet.)
Shale	"	2	"	52, (the thickest mass, 130 ")
Limestone	"	$2\frac{1}{2}$	"	9, (the thickest mass, 40 ")
Clay	"	3	"	8, (the thickest mass, 28 ")
Coal seams	"	1	"	50 to 60, (the greatest thickness of a coal seam, 13 feet; average, $3\frac{1}{2}$ feet.)

The limestones are situated in the lower half of the basin, thickening toward the south-east, in which direction the coal measures grow thinner. It is in the lower limestone strata that the plants and fish remains were found at Burdie House by Hibbert. In the upper series of coals *unionidæ* occur.

The shales contain continuously stratified ironstone ("black band"), and interrupted courses of nodular ironstone, each nodule generally containing organic matter as the nucleus of aggregation.

The district is greatly traversed by faults or "slips;" 120 are mentioned; 110 marked on the map; one affecting the level of the beds 400 to 500 feet. Of 109 slips, 94 range between the north and west points of the compass; 7 run due west; the total effect, of 78 slips, being 35 downthrows to the south, 385 fathoms, and 43 downthrows to the north, 754 fathoms. The slips do not range parallel to the outcrop.

The district is surrounded but not penetrated by large trap bosses; the coal seams rise sharply toward them, as if to pass over—having been uplifted *with* them, rather than *by* them. Greenstone dikes

of considerable breadth divide the coal. Along these, and especially along the Niddry dike, which runs east and west, nine or ten miles, the usual *hardening* of sandstone and shale, *carbonization* of coal, &c., occur; but there is usually *no dislocation* of the strata on the line of the trap dike. The coal seams, on the average, thicken toward the north. The lower limestones thicken toward the south. On the whole, allowing for waste, unattainable portions, and other circumstances, this one district may be admitted as likely to yield to the miner, for actual use, 2,250 millions of tons of coal—the annual home consumption of Great Britain being (1839) estimated at thirty millions. The coal is partly "splint," partly "rough" or "cheery," partly of the "cannel" or "parrot" variety—the first containing most oxygen; the last most hydrogen and nitrogen, and the least carbon. The splint has a long slaty structure; the cheery coal is more cubical; the cannel coal is of more compact and uniform texture, and still more nearly cubical.

In Fife, one of the coal seams at Dysart is 21 feet thick, and there are three others which exceed 10 feet. In the western part of the Scottish coal basin we may notice two main working districts in Lanarkshire and Ayrshire. Mr. Craig* has presented us with a useful summary of some of the phenomena. He classes the strata in the following order:—

Upper Red Sandstone series.
Upper or Freshwater Coal series.
Upper Marine Limestone series.
Lower Coal series.
Lower Marine Limestone series.
Old Red Sandstone.

The upper red sandstone group, consisting of red and variegated sandstones, shales, and thin coal seams, is supposed to be somewhat unconformed to the subjacent group. It spreads extensively in Lanarkshire and Ayrshire.

In the upper or fresh water coal series, which is often tinged red, lie about thirty seams of coal, of which seven or eight are workable, from two-and-a-half to ten feet thick, in an area extending from Glasgow to Carluke, twenty miles long, and from six to fifteen broad. This district yields splint and cannel coal, but the greater part of the seams is of the more cubical varieties. Ironstones of the black band variety occur in three parts of this section, from fourteen to twenty-two inches thick. Unionidæ occur abundantly; megalichthys Hibberti, and gyracanthus, with the usual plants of the coal formation; lepidodendron, sigillaria, stigmaria, asterophyllites, sternbergia, &c. Trees occur in situ.

In the parish of Cambuslang, the following section occurs:—

* Reports of British Association for 1840.

	Feet.	Inches.
To the first coal	85	0
Soft coal	4	6
To the second coal	26	6
Soft coal	3	6
To the third coal	63	6
Shaft coal	5	0
To the fourth coal	65	2
(Ironstone here.)		
Soft coal	6	0
To the fifth coal	83	0
Soft coal	3	0
To the sixth coal	10	0
(Ironstone here),		
Hard coal	3	6
Parting	1	6
Soft coal	1	6
Beds below explored	84	0
	445	8

The upper marine limestone series, about two hundred yards thick, contains only two or three thin seams of coal, and three or four limestones, with shales, which yield crinoidea, nuculidæ, euomphali, bellerophontidæ, orthoceratidæ, &c.

The lower coal series contains no limestone, but several coals, the lowest being a cannel coal two to three feet thick, above which, fifteen fathoms, is the main coal. Black band ironstones, from ten to sixteen inches, lie in this group,

At the bottom of this series are many courses of ironstone nodules, with separating sandstones, and occasional thin limestones.

The lower limestone series contains, besides the limestones, aluminous shales, and a sulphurous coal seam—the whole resting on the old red sandstone.

This series is found again in Ayrshire, yielding six or seven workable coals, from two-and-a-half to seven feet thick—a black band of ironstone, and several courses of nodular ironstone. Marine limestone underlie these coal measures.

Fresh water shells, accompanied by nodular ironstones, and numerous reliquiæ of equisetiform and filicoid plants occur *without limestone* beds in the coal fields of Clackmannanshire, Falkirk, and St. Andrews, but most of the Scotch coal fields, like that of the north and west of Northumberland, are formed by a development of the carboniferous limestone group of Yorkshire and Durham, and contain marine shells.

Carboniferous System of Ireland.

We now pass to Ireland, in which about half the whole area is occupied by rocks of the carboniferous system, which, if viewed on

the great scale, offer the same general associations as the great English and Welsh groups. The south of Ireland, as about Cork, shows almost the *same* sections as those of the western extremity of South Wales; the north of Ireland offers more analogy to the coeval beds in the north of England. The great area of the Irish carboniferous system unfortunately yields but little coal, the upper and more generally productive portion (*e*) being perhaps only recognizable about Dungannon and Ballycastle. Most of the coal about the source of the Shannon, near Kilkenny and Newcastle, is of the age of the millstone grit (*d*), or of the lowest part of (*e*). The greater part of the area is occupied by limestones and shales of the groups *a*, *b*, *c*.

Occupying the picturesque coast of Donegal Bay, Sligo Bay, and Killala Bay, and skirting the mountains of Connemara, the carboniferous system recovers the coast at Galway, and keeps it nearly to Dingle Bay. From this point, retiring inland, westward by Killarney to Mallow and Fermoy, it throws out branches and outliers to Kenmare, Clonakilty, Kinsale, Cork, Rathcormack, Dungarvan, Waterford, and Wexford, but the main outline turns again northward, skirting the mountains of Wicklow and Dublin, to the sea coast near the capital. It leaves the coast again near Drogheda, turning inland to Slane, Cavan, Monaghan, Armagh, and Donegal, and throwing off long digitations to Omagh, Maghera, and Lough Foyle, and outliers to Strangford Lough, Dundalk Bay, and Kingscourt. This immense field is broken by the older ridges of the Galtees, Tipperary, and other inland mountains. It is about 150 miles square! The result of Mr. Griffith's long labour on the carboniferous system of Ireland is indicated by the following summary:—

e	The coal series, but slightly represented.
d	Millstone grit series. It occupies a large space about the source of the Shannon, crowning with its huge blocks and crags the heights of Kulkeagh, and yielding coal, ironstone, and furnace grits to the iron-works on the western side.—500 feet.
c	Great shale series of Kulkeagh, with goniatites, posidoniæ, orthoceratites, bellerophontidæ, &c.—600 feet.
b	Upper limestone, cavernous, with coral bands in several stages. The calp series, gray and dark limestone, with shale and sandstone interposed in some districts. Lower limestone.
a	Carboniferous shale, locally rich in spirifera, strophomenæ, fish remains, &c. Yellow sandstone, with shale and occasionally limestone.

The upper parts of the series (*e d*) are most conspicuous in the country about Lough Erne, and the sources of the Shannon; about Kilkenny and Castle Conner; and in the elevated country on each side of the estuary of the Shannon. The true limestone series is of

amazing extent in the central parts of Ireland ; and the lower series arrives at its greatest importance in the southern tracts about Cork and Kinsale. Mr. Jukes has published* collective sections of this lower series, which show great variations in thickness, and great changes in the mineral aggregation. In Kilkenny county, at Knocktopher, the limestone rests on dark shale and yellow and brown sandstone, 150 feet thick. (Below these are red slates, and red and green argillaceous sandstone, with ferns of the genus sphenopteris and an ancodon ?)

Near Carrick-on-Suir we have, below the limestone, thin bedded yellow sandstone, and green and yellow shales, 150 feet ; (then alternations of yellow sandstone and hard red shale, 350 feet, unequivocal old red sandstone, &c., below 1800 feet.)

Farther west, in the same county, the upper beds of yellow sandstones and red shales thicken to 900 feet—(the whole series, including old red, 4500 feet.) In the northern part of the county of Cork, we have yellow sandstones alternating with red shales and slates, 500 feet. (Red shales and sandstones 400, and other red sandstones, &c., 2500.) South of Cork the series is thicker and more varied.

Here we have

	Feet.
Dark gray shales and slates, with occasional bands of greenish-gray grit	400
Brown sandstone, sometimes calcareous, and containing carts of Cucullæa?	50
Dark green shales and slates, weathering brown or yellowish, with occasional bands of hard sandstone, all more or less affected by slaty cleavage	600 to 1000
Red and green slates alternating	300
Red slates, with occasional yellow sandstone	500
Red slates, with gray or purple sandstones	2000
and the bottom not reached.	

Again at Kinsale,

Blue calcareous shales, with occasional thin bands of limestone and blue slates, with a few grit beds	2100
Blue strata, with greenish-gray grits predominating below	1700
Yellow sandstones, with shale partings	800
Red and green slates passing down into red slates and sandstones...	1500
(base not seen.)	

The three upper masses correspond to Mr. Griffith's carboniferous slate and yellow sandstone, and the whole suggests a strong analogy to the series of strata in the west of Pembrokeshire, already described : in fact, my own observations in this part of the country (1843) assure me of the affinity of the two districts. Mr. Jukes is desirous of referring all these groups to the Devonian system.

* Reports of the British Association, 1852.

The coal fields of Ireland, if we include in this term the millstone grit, occupy large tracts in that country, and are upon the whole analogous in general mineral characters and organic contents to those of England. The same absence of limestone, the same kind of succession of sandstones and shales, is remarked in them. Anthracite or stone coal, like that of South Wales, abounds in the Leinster and Munster districts; bituminous coal occurs in Connaught and Ulster. In Ulster the principal collieries are at Coal Island and Dungannon. The Munster coal district is stated by Mr. Griffith to be of greater extent than any English coal field, but it is much less productive. At Ballycastle the coal is found in connection with basalt.

Carboniferous System in Foreign Countries.

The carboniferous system of England and Wales is probably continuous under a part of the Channel, and connected underground with the northern range of coal deposits in France and Belgium. From Hardinghen, near Boulogne, this range may be admitted to pass under the secondary and tertiary strata of France, to Valenciennes, Mons, Charleroi, Liege, and Eschweiler; while frequently, from beneath, thick limestones show themselves, having the same organic remains as the mountain limestone of England and Wales, and stand in similar picturesque cliffs on the Meuse, about Namur and Huy. This valuable and extended but narrow field is folded in sudden anticlinals and synclinals. In the north-western, central, and southern parts of France, we have many spots of coal measures collected round or resting upon the tracts of older rocks, in Brittany, the Bourbonnais, Auvergne, and the Limousin. Near St. Lo, Quimper, and Laval; at Vouvan and Chantonnay, in Poitou; about Avallon, Decize, Autun, and Epinac; about Roanne and Lyons, the most productive being at St. Etienne and Rive de Gier. Again about Aubenas and Alais, on the right bank of the Rhone; and farther to the west, about Breves, Aubin, Rodez, Carmeaux, and near Perpignan; finally, about Toulon and Frejus, small coal tracts are known and partially worked. In general, the French coal fields, though they show below the true coal measures some beds analogous to our millstone grit and shales, only in a few places exhibit the mountain limestone. The strata are in fact often found in discordant repose on much older rocks.

Spain has also its detached coal fields in Catalonia, Arragon, and New Castile. Mr. Pratt has presented sections of these and older stratifications in the Asturias. Mr. Sharpe has noticed the coal of Portugal.

Returning to the Rhine, we find the Vosges to yield some traces

of coal near Colmar; and larger deposits at the foot of the Hundsrück, stretching from the Sarre at Sarrebrück nearly to the Rhine at Bingen and Mayence. Limestone is not here the general basis. Altogether, France may count about forty mostly small patches of coal, but according to Beudant,* whose summary we have given, only 1-200th of the whole surface is occupied by this precious group of strata.

Germany possesses several valuable coal fields. That on the river Ruhr, near Essen and Werden, (north of Elberfeld,) may be regarded as the eastern continuation of the Belgian deposit, emerging from beneath the very broad tertiary valley of the Rhine. It reposes on a valuable series of shaly or crinoidal limestones. In Bohemia, south of the Erzegebirge and Riesengebirge, is a large and valuable coal field, from which Count Sternberg extracted many beautiful plants. It is said to contain more than forty beds of workable coal. It extends eastward into Silesia, between Landshut and Silberberg. On the north-east and south-east of the Harz mountains detached coal fields occur; more valuable tracts are worked on the north side of the Erzegebirge, near Zwickau and Dresden. The extreme northern parts of continental Europe contain little that is important in regard to coal, of any age, and scarcely a trace of the true coal formation. In Russia Sir R. Murchison admits, at Koula and other places, only feeble and scattered developments of a true coal formation above the wide mountain limestone of that great country.

Farther to the east and south, Asia yields coal east of Heraclea, on the coast of the Black Sea; on the borders of the Persian Gulf; in China and India. The Indian coal fields of Cutch and Bundelkund; and on the Hooghly, at Merzipore and Burdwan; and on the Ganges at Bhangulpoor, will be of great importance when opened by railways. On Mr. Greenough's lately prepared geological map of India, many other patches of coal are marked, but their geological date is still in some cases undetermined. Some are apparently of the mesozoic era. Borneo possesses coal, and the Birman territory yields it of good quality, if not of great extent. It is abundant in Australia, on the Hunter River, and is not absent from Van Diemen's Land.

But it is in the northern parts of the American world that the most concentrated masses of coal occur—on a scale, indeed, corresponding to the other physical facts of that wonderful region. Nova Scotia and New Brunswick have a considerable quantity of coal, and of various quality, some, as that of the Albert mine, having little of the structure or appearance of coal, and being anthracitic. In several places the beds are thick (ten to forty feet). In the vast basin west of the Alleghany Mountains are very rich deposits of coal, anthracitic near

* Cours Elementaire, 1851.

the primary rocks and metamorphic ridges, bituminous at a distance from them. "The bituminous coal field, embracing the western part of Pennsylvania and a part of Ohio, extends over an area of 24,000 square miles, the largest accumulation of carbonaceous matter in the world. In fact, the bituminous coal measures can probably be traced almost continuously from Pennsylvania to the Mississippi, and even into Missouri, two hundred miles west of that river!"* Coal exists on the eastern slope of the Rocky Mountains: perhaps also on the western side of that great range.

In some instances a single seam of coal is sixty feet thick, and near the middle of the basin sixty-five seams have been counted. These vast coal fields, "extending from the north-eastern counties of Pennsylvania to the northern part of Alabama, and from the great Appalachian valley westward into the interior of Ohio and Kentucky, include only a portion of the original formation, immense tracts having been destroyed by denudation."† Upon a moderate estimate, its superficial area amounts to 63,000 square miles, fully ten times as great a space as all the *productive* coal fields of Britain! Wide coal basins of equivalent age, the same authority tells us, lie remote from the Appalachian chain, far to the north-west, viz., that in the state of Michigan, and that which occupies a part of Indiana, Illinois, and Missouri. Beneath a great part of the North American coal fields limestone is extensively spread, comparable in a remarkable degree to that of the British Isles, and containing many of its best known organic remains. Thus viewed on a great scale, the carbonaceous system is one of the most extensive, and furnishes very good evidence of the land and sea toward the close of the Palæozoic period.

General View of Circumstances under which the Coal Beds were deposited.

Few subjects in geology have been examined under more various points of view than the question of the origin of coal, and the circumstances under which it was deposited. We may wonder at the philosophical blindness which would permit in the last century protracted disputes concerning the vegetable basis of coal, when so many thousand plants converted into that substance were found in the shales and sandstones of every coal district. But in those days this kind of evidence was so little understood, that the inimitable impressions of ferns and other plants from which we are now accustomed to reason concerning the climate and other conditions of the ancient world, were not even admitted to be reliquiæ of the vegetable kingdom.

* Hitchcock's Elementary Geology.
† Rogers (Prof. H. D.) in Transactions of American Naturalists, 1843.

There is no necessity to enlarge upon the proofs of the origin of coal from vegetables, drawn from an examination of its chemical constitution as compared with vegetable products, and the composition of the ligneous parts of plants, and from the unanswerable identity of the carbonaceous substance, into which a vast multitude of fossil plants have been converted. The chemical constitution of this carbonaceous product of the individual vegetables, is exactly analogous to the chemical constitution of coal; and it is quite probable that hereafter the reason of the variations to which both are subject, whether dependent on the original nature of the plant or produced by unequal exposure to decay before inhumation or metamorphic subsequent operations, will be as apparent as that of the general agreement arising from a common vegetable origin.

Admitting then the vegetable origin of coal, the next question relates to the situation where the plants grew from which the vast mass of the coal seams was derived.

Many of the plants accompanying coal are of unknown types, and some are too imperfect to permit any botanical deductions; but the researches of naturalists have nevertheless been successful in determining some general characters of this ancient flora.

The greater number of these plants were decidedly terrestrial.

They appear to be often analogous to tropical tribes of vascular cryptogamic, and coniferous plants.

They grew then on the land, and it is probable from Brongniart's researches, that this land was in a high degree subject to heat and moisture, more so than perhaps even the coasts and islands of tropical seas, to the flora of which situations the coal plants present remarkable general approximations.

We may now venture upon the main part of the inquiry which relates to the origin of coal, *viz.* whether the plants from which coal was produced *grew in their present situations*, and were there submerged and buried beneath marine or fluviatile deposits, or were swept down to their present repositories *from distant situations* by land floods and other causes. To guide us in this inquiry the following data may be premised:—

The *generally uniform*, or *gradually varying*, thickness of the several coal seams over a very large area; and the many laminæ which compose them.

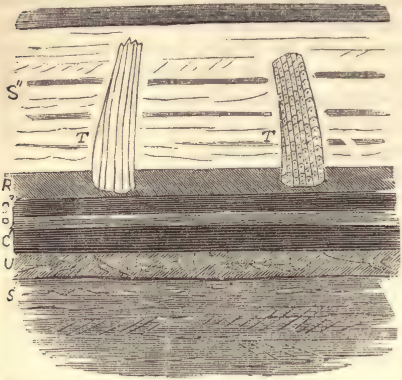
The peculiar kind of rock, usually indurated fire clay, below each bed of coal; with roots of trees (stigmaria).

The broken and fragmentary condition and confused intermixture of the plants which accompany coal strata, and their being frequently *without roots attached.*

The occurrence of the *same species* of plants in strata so dissimilar as shales, ironstones, and sandstones.

The fact that in some districts only land plants and *fresh water* shells and fishes occur in the coal strata; that in others very few plants and many *marine* shells occur, especially if limestone beds be present in the section.

The occasional vertical position of *broken stems* of large trees and reed-like plants (fig. 105).



105 *

The *parallelism* or conformity of the several beds of coal.

The extreme differences in the thickness of the several seams, and the occurrence of many *very thin plates of coal* through many of the coal shales.

The occasional occurrence in a coal seam of large quartzose boulders, unconnected with any other mark of agitated water.

Peat Bogs.—De Luc and several eminent geologists, especially Adolphe Brongniart, have supposed coal beds to have been originally a sort of peat bogs, or masses of vegetable reliquiæ accumulated round the place of their growth, upon which other vegetables grew, and that subsequently these tracts of country during some extensive convulsions subsided below their former level, and were covered by various mechanical deposits. This hypothesis seems to have been suggested by the seeming analogy in some respects between the chemical changes which have happened to the vegetable matter of peat bogs and of coal, by the occurrence of stems of plants vertically in the coal strata, and by the supposed difficulty of otherwise explaining the acknowledged regularity of the coal beds.

These circumstances certainly favour the hypothesis of De Luc, but they must make us overlook some difficulties in the way of adopting it.

The formation of *peat bogs* is, as far as we know, not always of the kind here supposed. There are indeed two principal modes by which the carbonaceous mass called peat is aggregated. It is not by fragments of trees and herbaceous plants accumulated round the place of their growth, but of a variety of successively dying mosses and other

* T Stems of sigillaria erect in (S'') sandstone, shale, &c., above (R) roof of coal, with plants &c., but not entering (C^2) top coal.
P Parting of shale (no marks of upright stems). C^1 Bottom coal.
U Under-clay with stigmarian roots. S' Sandstone, shale, &c.

moisture-loving plants that the peat bogs *grow up* to the extent which they occupy on the high cold hills of the north of England.

Subterranean Forests.—There is, however, another kind of vegetable accumulation which may be thought to throw more light on the origin of coal. The *turf or peat moors*, as they are called in the north of England, which occur in low ground toward the estuaries of rivers, and along the margin of the sea, in many parts of England, contain a mass of vegetable matter, composed of mosses and other humid plants, roots of ling, &c., and envelop trunks of trees, sometimes prostrated in particular directions, apparently cut by art or decayed by time. The roots are often seen in attitude of growth. In some places are oak, in others birch or fir, according, as William Smith has observed, to the nature of the soil below, which is sand, marl, or clay. With them often lie the remains of terrestrial quadrupeds, land shells, &c.

The marls sometimes contain fresh water shells, but never, in the English levels, marine exuviæ. In many places these accumulations of vegetable reliquiæ are below the level of the sea, sometimes greatly so, and covered by *various alternations* of mechanical deposits, sands, and clays brought down by the rivers or deposited by the tide.

These phenomena appear to admit of an easy explanation, if we allow that the relative level of the sea and land has been locally subject to variation, and thus the drainage of the country deranged.

The greatest part of the vegetable mass grew in its present situation; it was a *humid forest* where the leaves and branches of the trees, mingling with the herbaceous covering at their base, formed an extensive carbonaceous mass, which enveloped the trees when they fell by any great violence of wind or flood, perished by natural decay near the base, or yielded to the axe of the old inhabitant. In cases where the situation was elevated, or otherwise removed from the action of the tide, the ancient forest has been sometimes converted to a lake, or overwhelmed with the ruins brought by a land-flood. Along the side of great rivers, where the level was permanently below the floods or tides, many successions of sandy and argillaceous deposits have taken place, and sometimes a second accumulation of vegetables; and thus the whole alluvial *sediment and subterranean forest* resembles in some important respects the alternations of earthy deposits and carbonaceous layers which compose the ancient coal strata.

Lake Deposits.—We have, however, not yet exhausted the heads of the subject of the agglomeration of vegetable reliquiæ. In many situations in England, as in Holderness,* they have been swept down from the land, and accumulated on the beds of lakes in a pretty regular stratum of partly decomposed leaves and herbs, with branches of hazel bushes, nuts, &c., and fragments of larger trees. Over them

* Geology of Yorkshire, vol. 1, *passim.*

the lake has since diffused, in regular layers, the sediment brought into it by the streams and floods, with the shells which lived in the waters.

River Deposits.—The Mississippi and other great rivers of the world whose banks are clothed with immense primeval forests, whence, from age to age, the trees as they fall are rolled away by the periodical inundations, deposit in their wide mouths *alternate* and repeated layers of vegetable and earthy matter, and thus present us with another analogy to the coal strata not less exact in detail than any of the preceding, and perhaps as justly comparable in extent of effect.

To what distance in the sea trees may be rolled by the mighty continental floods, those who have been accustomed only to contemplate the trifling streams of England, can have no proper idea; but the navigator who at the distance of two or three hundred miles recognizes in the Atlantic the last effort of the current of the Amazons, or in the Bay of Bengal observes the immense accumulation of earthy sediment transported by the gentler waters of the Ganges, will readily admit that the estuary deposits from such rivers may exceed the area of the most extensive coal basins of Europe.

Effects of Higher Temperature.—If we are right in the inference that the ancient flora which lies buried in our coal tracts was the growth of even more than tropical heat and moisture, we may readily conceive how these circumstances, joined to the certain fact that the land was then of far more limited surface, would also explain the *greater amount* of both the organic and inorganic depositions from the ancient drainage of the earth. For a higher temperature of the air and earth, accompanied by more abundant moisture, would naturally be followed by more luxuriant vegetation, more abundant precipitation of rain, greater and stronger rivers, and more violently excited floods. As the rich vegetation and atmospheric storms and destructive floods of the tropical region exceed those of our colder latitudes, so would the effects of the ancient floods in still hotter climates surpass the most powerful results of the present combination of agents.

It is possible that the effect may have been heightened by some essential difference in the constitution of the atmosphere; (M. Brongniart supposes by a large proportion of carbonic acid;) but without at present entering these fields of hypothesis, the botanic characters of the fossil flora appear to warrant the conclusion above stated.

From this short review of the operations now in progress, by which a part of the decayed vegetable covering of the earth is accumulated in peat bogs, lakes, estuaries, and the sea, we perceive clearly that if the production of coal be not now actually in progress in certain situations, deposits of carbonaceous substances happen under circumstances which will greatly contribute to limit and simplify our notions of the origin of that combustible.

Coal formed in various Situations.—Until all the circumstances which characterize the different coal basins have been very fully investigated, it will be hazardous to decide *generally* against any hypothesis advanced to explain the deposition of coal, which proceeds upon observation of the accumulations of vegetable matter now in operation. It may hereafter appear that the vegetables of some coal basins grew where their remains are now carbonized, according to M. Brongniart's notion; that other coal beds arose from trees and plants, swept down from the land into fresh water lakes; that others were formed in estuaries alternately traversed by floods from the land and tides from the sea; and that some land plants were transported far into the deep and tranquil ocean.

Till within a few years, the weight of opinion, if not of observation, was decidedly in favour of the opinion that the *greater portion of all the carbonaecous* deposits were swept down from the places where they grew on the land, to ancient lakes, estuaries, and seas; and, indeed, it was perhaps not thought *probable* that any continuous bed of coal had been produced otherwise.

Not always where the Plants Grew.—De Luc's notion of all the plants growing in the very spot where they have been converted to coal was thought inapplicable to cases where many layers of coal alternate with many of sandstones, shales, ironstones, &c. For this could only have happened, according to that notion, in consequence of at least as many subsidences and subsequent desiccations of the same tract of strata, as there are coal seams in it; and when in addition we take into account the perfect parallelism of the strata indicating no disturbance, the thin laminæ of coal which sometimes occur in the shales, the local divisions of the seams of coal, and the quantity of land plants lodged in the separating strata, we shall be compelled to admit that the hypothesis involves difficulties of no common order.

On the contrary, it was contended, these very circumstances seemed to be exactly such as might be occasioned by the effects of periodical floods operating through a long succession of time upon a well-wooded country. They would transport at intervals vast quantities of vegetable and mineral matter into the lowest receptacles of water. There the mingled mass would be *sorted by the waters*, according to bulk and specific gravity, as we observe every day in lakes and on the sea shore, an effect which most probably would be much heightened by the unequal velocity with which masses of such unequal bulk and gravity would be originally transported by the current. They would be deposited in distinct layers, of which the *most regular and uniform* would be the layers of plants, because these are more different both as to bulk and specific gravity from the other materials brought along by the stream, than are these materials among one another; a fact *remarkably conformable to observation.*

But though the greater mass of the plants would be thus separated from the earthy sediment, there would probably be some portion unavoidably entangled therewith and deposited with them, and thus the sandstones and shale are found to contain in confused admixture a considerable number of plants.

The trees thus transported by the floods might for the most part not have been uprooted; they would also in their course be broken and mutilated, and mostly deprived of branches and leaves, exactly as we frequently find them in the coal strata.

In the various eddies of the waters under which the sediment fell, some trees might be reared upright, and others might and indeed would float with the heaviest end downward, and be kept in that posture by a sudden and great accumulation of sediment, and thus we seem to have a natural explanation of the inclined, if not vertical position of trunks of sigillariæ, and equisetaceæ in sandstone. In shale deposited more tranquilly, this fact has never or most rarely been noticed.

Successive operations of this kind would equalize the results over a large area, and produce a remarkably general parallelism of strata in the *same basin.*

According to the condition of the currents, the accumulations at any given time, or for any period, might be in one part wholly vegetable, in another wholly earthy, or of alternate quality, and thus the occasional *deadness of a part of a coal tract usually productive*, the division of a coal seam into its constituent portions, and the partings of a coal bed, appear all perfectly natural consequences of the same simple cause.

Such, twenty years since, appeared a probable general view of the origin of coal, from plants drifted by water to particular repositories. We have left them nearly as they were then expressed, for the purpose of showing that they still retain much force, and admit of being now combined with more recent discoveries into a larger and more general view. The most important of these discoveries establishes as a fact, that certain kinds of trees, whose remains abound in the coal tracts, as Sigillaria and Lepidodendron, did *actually grow* in several regions on the very spots where the coal strata are accumulated. At Dixonfold, near Manchester, and the South Joggins' Cliffs of Nova Scotia, many of these trees appear in the *attitude of growth*, their *roots* in and below a bed of coal, their stems piercing at *right angles* the *strata* above. In Nova Scotia, many repetitions occur of this phenomenon in the same cliff, indicating many successive growths of land plants, on strata successively deposited from water. In these strata a land shell (Pupa ?) and a lizard were found.

In these cases we find proof of land existing in several distinct periods, and on the same geographical area; this land might be, pro-

bably was, marshy, or on the edge of marshes; it nourished round them, by the falling of other trees, perhaps by the drifting of other plants, the mass of carbonaceous matter was accumulated, which now represents a coal seam. The area actually occupied by one great coal seam in North America, the "Pittsburg seam," from three to fourteen feet thick, along and west of the Appalachians is 14,000 square miles; and allowing for denudation between detached points, 34,000 square miles are much less than its whole primeval extent. This is a larger area than that of Scotland or Ireland.*

In this immense area, the coal seam is not a simple mass, but divided into three main parts, the lowest is a pure coal, the middle is a bed of fine clay, and the roof coal is composed of alternating layers of coal and fine clay. This kind of formation is very common in all coal fields, and we learn from it that each coal bed is the fruit of interrupted and renewed accumulations of vegetables, the interruptions being marked by fine sediments, implying *distant* agitation of water. Finally, in *all coal beds*, are very many thin alternations of pure coal and impure coal, with not seldom thin laminæ of clay, impressed with the surfaces of plants above and below, and in some cannel coal beds are layers of fresh water shells. Then followed the drifting of sands and finer sediments, over the same area—watery action of some kind—occasioned, to speak in harmony with other geological facts, by *local subsidence* of that land. This ceasing, forests again overspread the same area, to be again covered up by watery action bringing sediments, in consequence of *further subsidence*. Nor must we limit this explanation to the examples in which the trunks of trees are found standing in sites above coal; the same conclusion may be admitted where the clays under a bed of coal contain roots of the same sorts of trees. Now, this has been shown by Mr. Logan† and others to be a very frequent, almost strictly general phenomenon in the true coal measures, above the millstone grit of South Wales, Nova Scotia, Derbyshire, Staffordshire, &c. Even where these are absent, or infrequent, the conformity of coal seams to a general type, in respect of the peculiar subjacent clays, makes it probable that similar causes are concerned in the production of them.

If we attempt to trace the process by which the great result was attained, it will soon appear that enormous periods of time must have elapsed during even the aggregation of *one coal seam*, if all the plants in its mass grew on the spot. Assuming, with Liebig, that plants, deriving their carbonaceous elements from the air, fix annually in their substance 1 lb. English for 24·4 square feet surface of

* H. D. Rogers in Trans. of American Geologists, 1840-2. He supposes the full original area to have equalled 90,000 square miles.
† Geological Proceedings, 1840, 1842.

ground, and further, that all this was preserved in a peaty deposit, growing up from them and under them, it would require 170 years to gather one inch of anthracite coal, and the enormous period of 122,400 years to accumulate 60 feet of the same.

In the earlier ages of the world, the growth of plants in northern zones may be supposed to have been of tropical luxuriance, and thus the period be shortened ; and we may admit that some of the plants were drifted, and that would further contract the time; but under any aspect, it must be concluded to have been very long.

The substance of coal, examined by the microscope,* shows often the characteristic structure of coniferous wood, also the textures of other trees and plants. The ashes disclose similar woody textures, and if we mistake not, much merely cellular tissue in the Staffordshire and Midland counties coal.

Bowman, Hawkshaw, Buckland, Lyell, and Rogers, to name no more, have signalized themselves in late years by attempts to combine the large series of data now collected regarding coal into a clear view of its physical history. In the following sketch we present only the salient features of the subject, as they stand at present:—

1. Conceive, toward the mouth of some great primeval river, or in some inland lake, or along some part of the sea shore, an area which is undergoing *accretion of sediment*, by periodical rather than gradual watery action.

2. Let the violent period of these accretions have passed, and let the area have received a general and nearly level deposit of the latest and finest sediments; this is the *under-clay*—the-stigmarian bed—mostly without shells, fishes, or ferns, not laminated, and rich in fine silica.

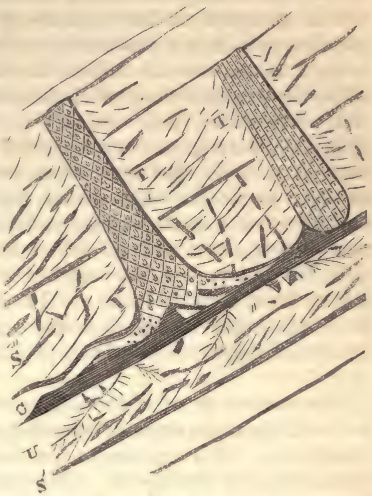
3. If it be a great inundation, which is now supposed to be passing away, from the river mouth or the lake, the clay might be so nearly drained and otherwise so circumstanced as to support *superficial* aquatic plants (Rogers), or to allow the growth of land trees, and be penetrated by their roots (Bowman). In the former case, in a moist tropical climate, marshy or peaty plants, (as Rogers, following Buckland,† supposed the stigmaria to be) the plants might be conceived to have grown quickly over an immense area, as the Anacaris Alsinastrum is doing in our modern canals and rivers. The parts of them more or less mixed with fine sediments, might be continually gathered in a peaty mass over the area, and from time to time oppressed by thin laminæ of such sediments, furnished by agitation of the water.

4. Trees might grow on the peaty mass and be thrown down, partly in it, but more especially on the top of it, with ferns and

* Hutton, Fossil Flora of Great Britain, confirmed by Quekett, and other authors of later date.
† Address to Geol. Society, 1841.

many other plants, the latest growth of the marsh, pressed flat and enveloped in *laminated shale*, or retaining their figure in nodules of ironstone. This is the *roof* of the coal, and in it not unfrequently lie unionidæ, cyprides, and fish remains, indicating the presence of water, under different conditions from those which accompanied the stigmarian under-clay. It is, in fact, the commencement of a series of deposits, which mark a *subsidence* of the area.

5. This subsidence brings in stronger currents of water, and their direct consequents, beds of sandstone, coarse or fine grained, with parallel or oblique lamination, and in these a few scattered plants, especially stems more or less fragmentary, irregularly placed, of sigillaria, lepidodendron, or coniferous trees. But sometimes the stems are in their place and attitude of growth, *over thick coal seams*, and sinking into them, or even passing through them, *if thin*, to the stigmaria, which are their roots, below. These were enveloped and sustained by the sediments, and the scattered and fragmentary plants *brought with them* by the force of water.



106 *

6. This period of watery agitation and accumulation of sediments passed, the surface is again in the condition first assumed, subaqueous, or partially dried, the uppermost bed being the almost uniform under-clay, on which, and in which, vegetation is re-established. When sigillaria (represented by these roots called stigmaria) grew on the under-clay, we may believe it to have been nearly or within a few feet or inches of the surface. If the vegetable accumulation round them is thin, that is, occupied a *short period of time*, the stems sometimes remain attached to the root; but if the accumulation is great, that is, *occupied a long period of time*, the stems do not penetrate the coal, and do not remain attached to their roots, except these roots be above or in the uppermost part of the coal.

7. When in the course of these changes the materials furnished

* T Stems of Lepidodendron and Sigillaria erect in (s″) sandstone, shale, &c., and spreading roots in and under the thin coal c.
V Under-clay with rootlets. s′ Sandstone, shale, &c.

by vegetation were slowly, but completely disintegrated in water, by eremacausis, without being pressed by incumbent earth, fishes and shells might leave their remains in the coal, as happens in the cannel of Wigan, which, however excellent as fuel, is rather a fine carbonaceous mud, than a truly laminated coal.

8. The under-clay is usually of a white or pale bluish colour, and contains little or no peroxide of iron, a circumstance now understood to be the effect of deoxidation, by decaying vegetable matter.

The reader may consult for further details on this subject the interesting papers on the South Joggins coal deposit, by Logan, Lyell, and Dawson, in the Proceedings of the Geological Society. He will remark as an essential, indeed the fundamental point in the explanation, the frequently repeated subsidence of the area; this, as being a well established and ordinary geological event, proved by many examples, may be at once accepted as true. As a necessary result, *drifting of earthy and vegetable materials from the land* follows. Thus, in some particular cases where the coal beds are the least regular, and have no true stigmarian under-clays (as in some of the coals of the millstone grit and mountain limestone), we may rather believe, with Sedgwick, that the coal bed is a drifted mass than the accumulation from growth in situ. In all cases we must attribute to this cause the scattered plants in the coal strata, and some share in modifying the aggregation of the plants which really did grow on the spot.

One curious proof of the action of such currents has been already noticed, the occurrence of rounded boulders of quartz rock or hard sandstone. This appears *in the coal* of Newcastle, and in that of Norbury, near Stockport. There being no other indication of *violent* currents which might drift such large masses, this has been found somewhat hard of explanation. Perhaps the following simple observation may meet the case. Trees with branching roots sometimes pick up and entangle in their growth large and small stones and other objects in the ground. These are to be seen where trees grow by watersides, or from other causes have their roots exposed. Conceive such a tree drifted, and deposited, and decomposed, the stones floating and carried along with it would be enveloped in the mass of matter formed by and around the tree. This implies, perhaps proves, in the case even of pure coal, resting on stigmaria clay, some influence of drifting for the accumulation of the mass.

It is probable that in lakes which receive floods overcharged with sediment, and which in consequence are frequently muddy, few kinds of mollusca, or fishes, or other animals would live, and that the molluscous remains would be such only as belonged to bivalves, like unio and anodon, or univalves, like paludina, which never come to the surface for respiration, but remain at the bottom of the waters. The

shells found in coal tracts, supposed to be of fresh water origin, are principally unionidæ and anodontidæ.

It is also probable, for the same reason, that only a small number of the animals or plants actually existing in the sea at any one time would be found within the area of a very muddy estuary, and thus we see the reason why the coal basins which contain no fresh water shells, and are from other circumstances presumed to be of marine origin, are most frequently devoid of animal remains, except in the calcareous layers or nodules which may occur in them. These calcareous deposits evidently mark periods during which the chemical precipitations from the sea were little or not at all troubled by the mechanical aggregations from the floods of the land.

As many basins of fresh water, estuaries, or seas, as received the vegetables and sediment brought down by the floods, so many distinct series of carbonaceous and argillo-arenaceous deposits would be produced; there would be no *particular agreement* between them in the number, thickness, quality, and arrangement of the coal seams, rocks, or shales, or ironstone, but a *general agreement*, depending on the common physical conditions of the region. But in the *same basin*, even over very large areas, there would frequently occur *particular agreements*, in many respects; coals of particular quality, rocks of certain kinds, beds of ironstone, and layers of shells, may be traced over large tracts and assigned to definite places in the general section.

Convulsive Movements of the Carboniferous System.

Nothing appears more clear in geology than that the same parts of the globe have been alternately subject to gradual alteration, through the slow and equal action of the ordinary system of nature, and to sudden extreme changes induced by the shorter dominion of violent disturbing forces.

The preceding descriptions sufficiently show how regular was the action of the causes which permitted the immense accumulations of chemical deposits, earthy sediment, and vegetable reliquiæ, on the beds of ancient lakes or estuaries, and for how long a period this process continued, the prodigious number of alternations in the deposits sufficiently attests. It was, indeed, compared to the present state of things, a period of remarkable excitement as to the vigour of vegetation, and perhaps also as to the abundance and force of inundations; but the parts of this series, compared with one another, and with analogous strata of different ages, furnish proof that the whole was the result of what may be termed the then ordinary course of natural operations.

Extent of these Disturbances.—But this long period appears to have

come suddenly to an end, and the characteristic regularity of its deposits to have been interrupted by a general eruption of disturbing forces which have left the traces of their power and extent in all the coal fields of Europe and America. As after the deposit of the slates violent dislocations happened and were succeeded by the old red conglomerate, so after the deposit of the coal, similar and equally extensive interruptions of the planes and courses of strata were followed by the analogous deposit of lower Red sandstone. In the course of these operations, the whole thickness of at least the stratified mass of the crust of the globe appears to have been broken in many directions, so that the divided portions were raised or depressed a few inches, many yards, or hundreds of fathoms from their former level, and placed in new situations, with various angles of inclination to the horizon and in various directions. Scarcely a mine or colliery is worked in strata of this era in any part of the world which is not crossed by several faults or dislocations of this nature, and it is always found that they divide and displace in the same direction the whole series of the strata to the greatest depths which man has reached.

That these dislocations happened after the complete deposit and induration of the coal strata is evident; that they followed almost immediately, and happened nearly at the same period of time, in almost all the coal tracts, appears certain from the general fact, that the disturbances of the coal seams rarely extend into the newer strata of magnesian lime and Red sandstone. There was, therefore, a general disturbing agency employed to break up the consolidated planes of the carboniferous strata; and from the occasional filling of the dislocations with basalt, various crystallized minerals, and other igneous products, no doubt can remain that the principal agent was that general source of heat which is included within our planet, and which finds vent for its energies in different places at different times.

To particularize all, or even the most remarkable of the faults of the carboniferous systems of different countries, and to notice all the variations of their appearance, would be entirely foreign to the intention of this treatise; such details must be sought in special descriptions of the several mining districts and coal fields. But we shall notice some of the most predominant of these dislocations, which appear to have caused the most extensive alterations in the level of the strata, and to have been most efficient in uplifting particular ranges of land, and giving new boundaries to the ocean.

That most of the carboniferous deposits were originally limited in area, has been already stated, and therefore we must be cautious not to infer the *violent* separation of two coal tracts from the mere fact of their disunion, without reference to the connecting inferior strata.

Thus the coal fields of the Forth and the Clyde were probably limited by the previous elevation of the ranges of the Grampians and the Lammermuir, and though presenting strong analogies with the northern coal fields of Northumberland, there is no reason to affirm that they were ever joined to them. Keeping this in view, and guided by a knowledge of the *characteristic points* of the several systems of strata, we shall be able, with more or less facility, to determine the amount of the disturbance of position induced on any given coal tract, and thus to restore in imagination the original condition of the strata. The separation of the great coal fields of Northumberland and Durham on the one hand from those of Yorkshire and Derbyshire on the other, appears to have been caused by a general elevation in an eastern and western range of the whole of the tract intervening between Wharfdale and Teesdale. In consequence of this and the *waste of the elevated surface*, it happens that while the lower parts of the carboniferous system are connected, the upper parts are entirely divided, and the magnesian limestone lies level on the coal of Durham, and millstone grit of Nidderdale, and again covers coal in Airedale.

Pennine Chain.—Again, all the great northern carboniferous tracts are arranged with relation to an almost continuous northern and southern axis of elevation, from the mountains round the source of the South Tyne to Ingleborough, through Bolland forest, by Pendle Hill and the western border of Yorkshire, to the limestone district of Derbyshire, while the particular fields of Hartley Burn and Black Burton, depend upon two cross lines of *dislocation* or fault, the former passing eastward under the name of the main, or 90 fathom dike, from near Brampton to the sea side near Tynemouth, and depressing the strata to the north, while the latter ranges east-south-east by a remarkable line of slate rocks from Kirkby Lonsdale to near Grassington, and throws down to the south. The carboniferous rocks which surround the lake mountains have certainly been affected by elevations subsequent to those which in that district followed the deposit of slate, and anterior to the deposit of the superincumbent Red sandstone.

A large proportion of the mineral veins which divide the carboniferous limestone series of Aldstone Moor, and the mining dales of Durham and Yorkshire, range east and west, and may be reasonably viewed as lateral fissures proceeding from the main axis of elevation which they join nearly at right angles. The same direction at right angles to the continuation of the same principal axis of elevation is recognized in the veins of Derbyshire, some of which range to the north-east and others to the south-east, and, though with considerable variations, appears to prevail amongst the numerous faults or slips of the coal field of Yorkshire.

The great northern and southern axis of elevation of the carboni ferous series in Derbyshire is broken across on the north, near Castleton, and appears to be terminated on the south, near Bradbourn, by great cross faults; and the whole of the coal measures of Nottinghamshire and Derbyshire, on the east, and of Staffordshire on the west of the axis, are cut off by rapid dip or sudden depression to the south. It may be conjectured that the line of this depression is prolonged beneath the red rocks of Cheshire to the estuary of the Dee, and it is, perhaps, not improbable that the red marl and sandstone which fills the drainage of the Mersey covers a large extent of depressed coal strata.

Further researches may very probably ascertain the existence of several other buried coal tracts in the midland parts of England near the detached coal fields of Leicestershire, Warwickshire, and Staffordshire.

Forest of Dean.—The Forest of Dean is a singular basin of coal strata with a belt of mountain limestone and *old* Red sandstone, rising from a plain of *new* Red sandstone, and looking over the vales of Wye and Usk to the similar but more extensive district of South Wales. The general line of elevation in this immense coal field is east and west, and the strata dip from both the north and the south toward the middle; but Mr. Conybeare has shown that along the middle runs an internal axis of elevation, so that the coal field is a double trough.

The elevation of the Mendip Hills, and other tracts of carboniferous limestone in Somersetshire and Gloucestershire, as well as the curious faults in the collieries near Bath and Bristol, must be referred to the same epoch, for the superior strata of red marl and the oolites are unaffected by them.

This short review shows us what extensive changes in the relative level and area of land and water were effected in these regions immediately after the deposition of the coal strata, and similar results have been obtained from researches in various parts of Scotland, Arran, and other islands, and in the large coal tracts in Ireland.

Ardennes.—In extending our researches to foreign countries, we must remember that the exact date of the disruption of the strata is determined by limiting the epoch between the date of the formation of the strata broken, and that of the unconformed stratum next incumbent or adjacent. Thus on passing from the Ardennes mountains to Luxemburg, we descend from the elevated slate range to a horizontal mass of new Red sandstone, followed by lias and oolites; and in this case it is clear that the elevation of the Ardennes preceded the deposition of *new Red sandstone;* but where that stratum is absent (the general case along the border of these mountains,) we must be content with inferring that the epoch of the disturbance was

older than the *oolites*. On this account it is not easy to fix the date of the disturbances of the coal series of Belgium and the north of France more precisely than by saying, it was anterior to the *oolites*, since these are the oldest strata lying unconformedly over the coal.

The slips and dislocations of the carboniferous system almost invariably agree as to the direction of their slope, compared to the level of the strata, with the general law stated before; but there are a few cases of such extraordinary dislocation, as at Valenciennes and in Somersetshire, that the beds of coal and accompanying strata are bent into a sigmoidal flexure, and in part turned completely upside down. Lesser cases of flexure of beds are not unfrequent.

With respect to the degree of distinctness of the planes of the slip, we may remark that this depends very much upon the consolidation of the strata divided. Thus while in limestone and solid sandstone the planes or cheeks of the slip are clearly traced, they are almost obliterated in shales and thin bedded sandstones, either by a bending at the surface of a fracture, or by a filling up of the chasm irregularly with fragments from the sides. This applies even to the case of a mineral vein which crosses alternating strata of three different kinds, as in the mines of Aldstone Moor and Swaledale, where the metallic and sparry substances are crystallized in abundance in the open space between the hard cheeks of limestone and gritstone, but are far less plentiful in the obscure and contracted interval between faces of shale. In districts which appear to have been once remarkably subject to igneous eruptions, the fissures of the dislocations are often filled by basalt, both in the subjacent limestone and superior coal tracts, as in the counties of Durham and Northumberland; but the metallic ores and spars which properly constitute a mineral vein, and which abound so much in the limestone as to give it the name of metalliferous, are very sparingly found in the fissures of the coal tract.

Affinity between Veins and Rocks.—However it is to be explained, there certainly appears to be some affinity between the metallic matter of the vein and the nature of the strata which it traverses; and though no doubt can be entertained that the veins are posterior to their including rocks, the frequent passage of *strings of ore* into the neighbouring strata, occasional nidiform masses, and solitary crystals of the metallic substances embedded in the interior of the rocks, besides the very remarkable examples of crystals of blende, galena, &c., in the interior of brachiopodous bivalves, seem to prove that the metallic matter has been in these cases deposited by a kind of *secretion*. Nor is this supposition, which is strongly confirmed by observations in the slate districts of Cornwall, in the least inconsistent with what is known of the diffusion of metallic substances by gradual heat much below their melting points. Breislac and Henry mention cases of the transference and collection of metallic matter (copper)

at an ordinary roasting heat, and the well known example of titanium extricated from the melted iron of our furnaces leads to analogous conclusions. We may, therefore, very consistently maintain, that mineral veins are posterior to the strata which they divide, and yet allow that the transference of metallic substances may have been effected by the ordinary agency of heat, or the influence of electricity, so as to impregnate the strata under particular circumstances with the contents of the neighbouring veins. Such secretions of metallic substances then do not require us to admit the contradictory dogma that the veins occupying fissures are contemporaneous with the strata which have been split by these fissures.

The metallic substances usually yielded by the carboniferous limestone are most of the ores of lead, zinc, and copper, with oxides and carbonate of iron, and the vein-stuff, or matrix, is calcareous spar, fluor spar, sulphate and carbonate of barytes, strontianite, quartz, &c.

ORGANIC REMAINS—CARBONIFEROUS SYSTEM.

(Genera supposed to be confined to this system in Capitals.)

PLANTS.

ADIANTITES,	2	Newcastle.
Alethopteris,	7	Newcastle, Wales.
ANABATHRA,	1	Berwickshire.
ANNULARIA,	2	Somersetshire.
ANTHOLITHES,	2	Salop, Newcastle.
APHLEBIA,	1	Newcastle.
ASPIDIARIA,	5	Somerset, Yorkshire.
ASTEROPHYLLITES,	12	Newcastle, Salop.
Calamites,	17	Yorkshire, Lancashire, &c.
CARDIOCARPON,	2	Newcastle.
Carpolithes,	5	Jarrow, near Newcastle.
CAULOPTERIS,	3	Somerset.
Chondrites,	1	Salop.
CREPIDOPTERIS,	1	Newcastle.
CYCLOCLADIA,	1	Newcastle.
Cyclopteris,	8	Yorkshire, Salop, Newcastle.
CYPERITES,	1	Leebotwood, Salop.
DADOXYLON,	2	Newcastle.
DIPLOXYLON,	1	Yorkshire.
Endogenites,	1	Salop.
Equisetites ?	1	Lancashire.
Flabellaria,	1	Cumberland, Salop.
HALONIA,	5	Yorkshire, Salop.
HIPPURITES,	2	Newcastle, Dean Forest.
HYDATICA,	2	Yorkshire.
Hymenophyllites,	2	Newcastle.
KNORRIA,	3	Newcastle, Salop.
LEPIDODENDRON,	19	England, Wales, Scotland.
LEPIDOPHYLLUM,	4	Somerset, Newcastle.
LEPIDOSTROBUS,	4	Newcastle, Salop.

LOMATOPHLOYOS, . . .	1	Edinburgh.
LYCHNOPHORITES, . . .	1	Yorkshire.
Lycopodites, ...	2	Newcastle, Durham.
LYGINODENDRON, . . .	1	Ayrshire.
MEGAPHYTUM, ...	3	Newcastle, Scotland.
MUSOCARPUM, ...	1	Lancashire.
MYRIOPHYLLITES, . . .	2	Yorkshire, Durham.
Neuropteris, ...	23	England, Wales.
NOEGGERATHIA, . . .	2	Newcastle, Lancashire.
Odontopteris, ...	4	Yorkshire, Staffordshire.
Otopteris?	1	Clee Hills.
PALMACITES, ...	1	Salop.
Pecopteris, ...	27	England, Wales, Scotland.
Peuce, ...	1	Durham.
PICEA, ...	1	Durham.
Pinites, ...	5	Newcastle, Berwickshire.
PINNULARIA, ...	1	Salop.
PITUS, ...	2	Berwickshire.
POACITES, ...	2	Devon, Lancashire.
POTHOCITES, ...	1	Near Edinburgh.
PROTOPTERIS, ...	1	Whitehaven.
RHABDOCARPUS, ...	1	Newcastle.
SAGENARIA, ...	6	Yorkshire, Newcastle.
SELAGINITES, ...	1	Edinburgh.
SIGILLARIA, ...	22	Newcastle, Wales, &c.
SPHENOPHYLLUM, . . .	6	Somerset, Newcastle, &c.
Sphenopteris, ...	31	England, Wales, Scotland.
STERNBERGIA, ...	1	Scotland, England, Wales.
STIGMARIA, ...	3	England, Wales, Scotland.
Trigonocarpon, ...	6	Lancashire, Salop, Somerset.
Ulodendron, ...	7	Edinburgh, Newcastle.

AMORPHOZOA.

Tragos? semicirculare, . . .	1	Ireland.

FORAMINIFERA.

ENDOTHYRA, ...	1	Beetham Fell, Westmoreland, near Whitewell, &c.
Nodosaria, ...	1	Tyrone.
Textularia, ...	1	Yorkshire.

ZOOPHYTA.

Alveolites, ...	2	South of Ireland.
Amplexus, ...	5	Yorkshire, Derbyshire.
ASTRÆOPORA, ...	1	Northumberland, South of Ireland.
Aulopora, ...	3	South of Ireland.
Campophyllum, ...	2	Bristol.
Chaetites, ...	4	Yorkshire, Bristol, &c.
Cladochonus, ...	5	Derbyshire, Yorkshire.
Clisiophyllum, ...	8	Kendal, Derbyshire, Wales.
COLUMNARIA, ...	2	Derbyshire, Fermanagh.
Cyathaxonia, ...	2	Kendal, Derbyshire.
Cyathophyllum, ...	11	Yorkshire, Derbyshire, Somerset.
CYATHOPSIS, ...	2	Isle of Man, Scotland.

DENDROPORA,	1	Derbyshire.
Diphyphyllum,	3	Northumberland, North Wales.
Favosites,	3	Yorkshire, North of Ireland.
Fistulipora,	2	Derbyshire.
Gorgonia ?	2	Ireland.
HETEROPHYLLIA,	2	Derbyshire.
LITHODENDRON,	7	Yorkshire, Derbyshire, &c.
LITHOSTROTION,	8	Bristol, Salop, Wales, Ireland.
LONSDALEIA,	4	Derbyshire, North Wales.
MICHELINIA,	6	England, Wales, Ireland.
MORTIERIA,	1	Derbyshire.
NEMATOPHYLLUM,	4	Derbyshire.
PETALAXIS,	1	Ireland.
Sarcinula,	3	Derbyshire, Wales.
Stenopora,	3	Yorkshire, South Wales.
Strephodes,	1	North Wales, Bristol.
Strombodes,	3	Derbyshire, Yorkshire.
Syringopora,	5	England, Wales, Ireland.
Zaphrentis,	8	England, Wales, Scotland.

ECHINODERMATA.

PENTREMITIDÆ.

CODONASTER,	2	Yorkshire, Derbyshire.
Pentremites,	11	England, Wales, Ireland.

PALÆCHINIDÆ.

Archæocidaris,	5	Yorkshire, Derbyshire, Ireland.
Palæchinus,	5	Yorkshire, Ireland.
PERISCHODOMUS,	1	Wexford.

CRINOIDEA.

Actinocrinus,	23	England, Wales, Ireland.
ASTROCRINUS,	1	Yorkshire.
ATOCRINUS,	1	Ireland.
Cupressocrinus,	2	Derbyshire.
Cyathocrinus,	10	Yorkshire, Derbyshire.
DICHOCRINUS,	3	Yorkshire, Somerset.
EURYOCRINUS,	1	Yorkshire.
MESPILOCRINUS,	1	Yorkshire.
PLATYCRINUS,	25	England, Wales, Ireland.
POTERIOCRINUS,	20	England, Wales, Ireland.
RHODOCRINUS,	9	Yorkshire, Bristol.
SYCOCRINUS,	3	Yorkshire.
SYNBATHOCRINUS,	1	Yorkshire, Bristol.
Taxocrinus,	3	Fermanagh, Yorkshire.

ANNELIDA.

Arenicola,	1	Lancashire.
Sabella,	1	Ireland.
Serpula,	6	Manchester, Salop, &c.
Serpulites,	3	Lancashire, Ireland.
SPIROGLYPHUS,	1	Ireland.
Spirorbis,	4	Ireland.

CRUSTACEA.

ENTOMOSTRACA.

Bairdia,	2	Ireland.
Cypridina,	2	Ireland, near Edinburgh.
Cypris,	4	Newcastle, Lancashire.
Dithyrocaris,	6	Tyrone, Glasgow.
ENTOMOCONCHUS,	1	Yorkshire, Ireland.
Eurypterus,	1	Near Glasgow.
Limulus,	3	Salop, Derry.

TRILOBITIDÆ.

BRACHYMETOPUS,	3	Ireland, Derbyshire.
Cyclus?	1	Yorkshire.
GRIFFITHIDES,	5	Ireland, Northumberland.
PHILLIPSIA,	7	Yorkshire, Derbyshire, Ireland.

MACRURA.

Macrura?	1	Salop, near Birmingham.

INSECTA.

Corydalis, (Neuropt.)	1	Coalbrook Dale.
Curculionides,	2	Coalbrook Dale.

BRYOZOA.

Ceriopora,	6	Yorkshire, Ireland.
Diastopora,	1	Wexford.
Fenestella,	19	England, Ireland, Scotland.
Glauconome,	5	Yorkshire, Ireland.
Hemitrypa,	1	South of Ireland.
ICHTHYORACHIS,	1	Clare.
ORBICULITES,	1	Ireland.
Polypora,	8	Yorkshire, Ireland.
Ptilopora,	2	Yorkshire, Ireland.
Pustulopora,	2	Yorkshire, Ireland.
Retepora,	2	Lanarkshire, Ireland.
SULCORETEPORA,	2	Yorkshire, Ireland.
Vincularia,	3	Ireland.

BRACHIOPODA.

Athyris,	12	Northumberland, Derbyshire, Ireland.
Camerophoria,	3	Derbyshire.
Chonetes,	16	Northumberland, Westmoreland, Yorkshire, Wales, Ireland.
Discina,	6	Ireland, Yorkshire.
HYPODEMA,	1	Derbyshire.
Heptæna, &c.,	7	Yorkshire, Ireland.

Lingula,	6	Yorkshire, Derbyshire, Ireland.
Orthis,	12	Ireland, Yorkshire.
Pentamerus,	1	Ireland, Kendal.
Productus,	43	England, Scotland, Ireland.
Retzia,	1	Yorkshire, South Wales.
Rhynchonella,	22	England, Scotland, Ireland.
Spirifera,	57	The British Islands.
Strophalosia?	1	Yorkshire.
Terebratula,	3	Yorkshire, Ireland.

MONOMYARIA.

Avicula,	20	Yorkshire, Ireland.
Aviculopecten,	72	Ireland, Yorkshire, &c.
Gervillia?	2	Yorkshire, Fermanagh.
Inoceramus?	4	Ireland.
Lima?	1	Ireland.
Pecten,	3	Yorkshire, Ireland.
Posidonomya,	8	Fermanagh, Derbyshire.
Pterinea?	1	Tyrone.
PTERONITES,	5	Ireland.

DIMYARIA.

Anatina?	2	Ireland.
Anodontopsis,	1	Ireland.
Arca,	7	Ireland, Derbyshire.
Cardinia (unio),	5	England, Wales, Scotland.
Cardiomorpha,	4	Ireland, Yorkshire.
Conocardium (Pleurorhynchus),	9	Ireland, Yorkshire, Derbyshire.
Corbis?	1	Ireland.
Corbula?	1	Scotland.
Cucullæa,	3	Yorkshire, Ireland.
Cypricardia,	9	Ireland, Yorkshire, Northumberland.
Cyprina,	1	Ireland.
Dolabra?	6	Ireland.
Donax?	1	Ireland.
Edmondia,	13	Ireland, Yorkshire.
Leda,	8	Ireland, Derbyshire, Northumberland.
Leptodomus,	3	Ireland, Yorkshire, Lanarkshire.
Lithodomus,	2	Derbyshire, Northumberland.
Lucina?	3	Yorkshire, Ireland.
Lutraria?	1	Ireland.
Mactra?	2	Ireland.
Modiola,	16	Ireland, Yorkshire.
Myacites,	7	Ireland, Derbyshire.
Myalina,	6	Lanarkshire, Salop.
Mytilus,	3	Ireland.
Nucula,	14	Armagh, Northumberland, Salop.
Pandora?	1	Ireland.
Pleurophorus,	1	Weardale, Durham.
Psammobia?	1	Ireland.
Pullastra?	2	Ireland.
Sanguinolites,	15	Ireland, Northumberland.
SEDGWICKIA,	7	Ireland.
Solemya,	1	Northumberland, Ireland.
Teredo?	1	Ireland.

Unio,	7	Salop, near Edinburgh.
Venus ?	2	Northumberland, Yorkshire.

PTEROPODA.

Conularia,	1	Lanarkshire, Bristol.

GASTEROPODA.

Capulus,	9	Ireland, Yorkshire.
Cylindrites ?	1	Derbyshire.
Dentalium,	2	Ireland, Westmoreland.
DIRINUS,	1	Ireland.
Euomphalus,	21	England, Wales, Ireland.
Lacuna ?	1	Ireland.
Littorina,	1	Ireland.
Loxonema,	14	Ireland, Derbyshire, Yorkshire.
Macrocheilus,	16	Ireland, Yorkshire, Derbyshire.
Melania ?	1	Kendal.
METOPTOMA,	5	Derbyshire, Yorkshire.
Murchisonia,	9	Ireland, Yorkshire, Derbyshire.
Natica,	14	Northumberland, Yorkshire, Ireland, Salop.
Nerita,	2	Bristol, Ireland.
Patella,	8	Yorkshire, Ireland.
PHANEROTINUS,	3	Yorkshire, Ireland.
PLATYSCHISMA,	7	Ireland, Derbyshire.
Pleurotomaria,	38	Yorkshire, Ireland, Derbyshire.
Trochus,	2	Yorkshire, Derbyshire.
Turbo,	4	Yorkshire, Ireland.
Turritella,	8	Lanarkshire, Westmoreland, Salop.

NUCLEOBRANCHIATA.

Bellerophon,	23	Yorkshire, Ireland, Derbyshire.
Porcellia,	4	Lanarkshire, Yorkshire.

CEPHALOPODA.

Actinoceras,	1	Dumfriesshire, Ireland.
Cryptoceras,	2	Derbyshire, Yorkshire.
Goniatites,	56	Yorkshire, Ireland, Derbyshire.
Nautilus,	40	Ireland, Dumfriesshire, Derbyshire.
Orthoceras,	33	Yorkshire, Ireland.
POTERIOCERAS,	3	Dumfriesshire, Yorkshire.
TRIGONOCERAS,	2	Ireland.

FISHES.

Acanthodes,	1	Near Edinburgh.
Amblypterus,	4	Near Edinburgh, Ireland.
Asterolepis,	1	Armagh.
ASTEROPHTYCHIUS,	3	Armagh.
Carcharopsis,	1	Armagh.
CENTRODUS,	1	Lanarkshire.

CHEIRODUS,	1	Derbyshire.
Chelyophorus,	1	Ireland.
CHOMATODUS,	5	Armagh, Bristol.
CLADACANTHUS,	1	Armagh.
CLADODUS,	10	Armagh, Bristol.
CLIMAXODUS,	1	Derbyshire.
Coccosteus,	1	Armagh.
Cochliodus,	5	Armagh, Bristol.
Coilacanthus,	1	Halifax.
Colonodus,	1	Armagh.
Cosmocanthus,	1	Armagh.
Cricacanthus,	1	Armagh.
Ctenacanthus,	10	Armagh, Bristol, Dalkeith.
Ctenodus,	3	Yorkshire, Manchester.
Ctenoptychius,	8	Armagh, Glasgow, Manchester.
DIPLODUS,	2	Lancashire, near Edinburgh.
Diplopterus,	1	Yorkshire.
Dipriacanthus,	2	Armagh.
Eurynotus,	2	Near Edinburgh.
Glossodus,	2	Armagh.
Gyracanthus,	5	Scotland, Yorkshire, Wales, Ireland.
Gyrolepis,	1	Lanarkshire.
HELODUS,	11	Armagh, Bristol, Lanarkshire.
Holoptychius,	9	Near Edinburgh, near Glasgow.
Homacanthus,	2	Armagh.
Isodus,	1	Draperstown, Ireland.
Lepracanthus,	1	North Wales.
Leptacanthus,	2	Armagh, Derbyshire.
Megalichthys,	2	Leeds, Glasgow.
Nemacanthus,	1	Armagh.
Onchus,	6	Armagh, Bristol.
ORACANTHUS,	4	Armagh, Bristol.
ORODUS,	9	Armagh, Bristol.
Orthacanthus,	1	Leeds.
Osteoplax,	1	Ireland.
Palæoniscus,	7	Near Manchester, near Edinburgh.
PETALODUS,	0	Armagh, Derbyshire.
PETRODUS,	1	Derbyshire.
PHYSONEMUS,	2	Armagh.
PLATYCANTHUS,	1	Armagh.
Platysomus,	2	Near Edinburgh, Leeds.
PLECTROLEPIS,	1	Lanarkshire.
PLEURACANTHUS,	2	Leeds, Dudley.
PLEURODUS,	2	Lanarkshire, Reeabore.
PŒCILODUS,	8	Armagh, Lanarkshire.
POLYRHIZODUS,	2	Armagh.
PSAMMODUS,	4	Armagh, Bristol.
PSAMMOSTEUS,	2	Ireland.
Ptycacanthus,	1	Near Edinburgh.
Pygopterus,	3	Near Edinburgh.
RHIZODUS,	1	Near Edinburgh.
SPHENACANTHUS,	1	Near Edinburgh.
TRISTYCHIUS,	2	Lanarkshire, Fermanagh.
URONEMUS,	1	Near Edinburgh.

REPTILIA.

PARABATRACHUS,	1	Lanarkshire?

The carboniferous system may now be compared in respect of its various groups of life with the older groups of the palæozoic strata. Taking 1,000 for the general numerical term of comparison, we find the following proportional numbers of species in the several groups :—

			Proportion to 1,000.	Proportion to 1,000 Plants.
Plants	286	—	176*	omitted.
Amorphozoa	1	—	1	1
Foraminifera	3	—	3	2
Zoophyta	114	—	70	85
Echinodermata	127	—	79	96*
Annelida	16	—	9	11
Cirripedia	0	—	—	—
Crustacea	36	—	22	27
Insecta	3	—	2	2
Bryozoa	53	—	33	41
Brachiopoda	191	—	117	143
Monomyaria	116	—	71	86
Dimyaria	166	—	102	124
Pteropoda	1	—	1	1
Gasteropoda	197	—	121	147*
Cephalopoda	137	—	85	103
Fishes	174	—	107	130
Reptilia	1	—	1	1
Aves	0			
Mammalia	0			

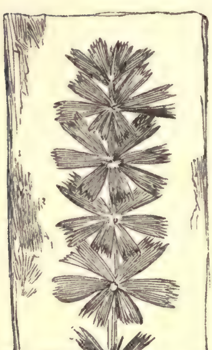
Here we find, in accordance with the preceding groups, zoophyta, brachiopoda, gasteropoda, and cephalopoda numerous ; but crustacea have lost their importance, brachiopoda and fishes are at least rivalled by the gasteropoda, while echinodermata have sprung up to overmatch the zoophyta, and dimyaria become numerous. The largest group of all is formed of land plants. If these be omitted, the numbers for the other classes may be more fairly compared with those given in preceding tables.

CARBONIFEROUS SYSTEM.

107

108

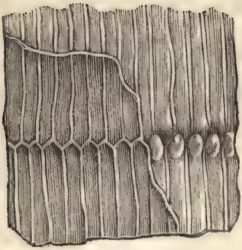
109



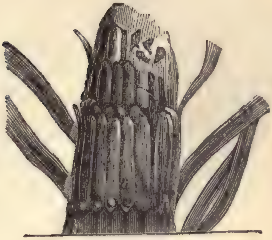
110

111

107 Pecopteris aquilina.
108 Sphenopteris Hæninghausii.
109 Neuropteris Loshii.
110 Sphenophyllum dentatum.
111 Annularia brevifolia.



112



113

114

115

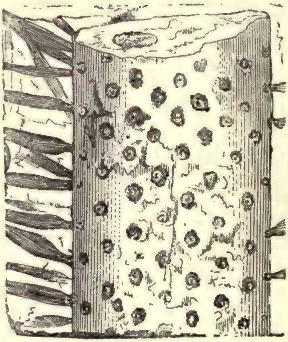
112 Calamites Suckovii.
113 Calamites cannæformis.

114 Lepidodendron crenatum.
115 Lepidodendron elegans.

116

117

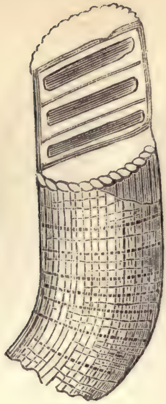
118



119

116 Walchia Schlotheimii.
117 Walchia hypnoides.

118 Sigillaria pachyderma.
119 Stigmaria ficoides.

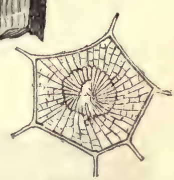


120

121

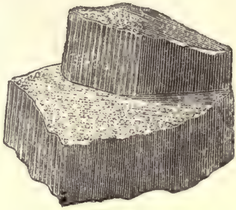
122

123

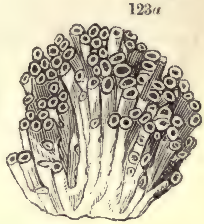


123*a*

125



124



124*a*

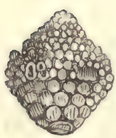
120 Amplexus coralloides. 122 Cyathophyllum regium. 123*a* Cross section of a cell.
121 Clisiophyllum turbinatum. 123 Lithostrotion basaltiforme. 124 Chaetites depressus.
124*a* Syringopora geniculata. 125 Cyathocrinus planus.

126

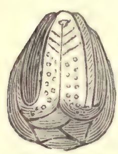
127

128

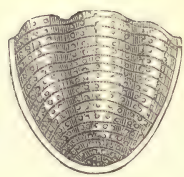
128*a*



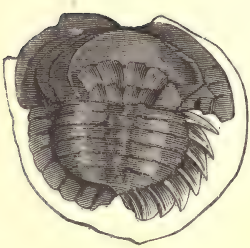
129



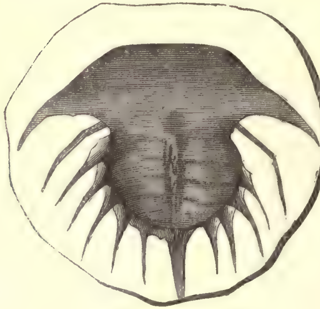
130



131

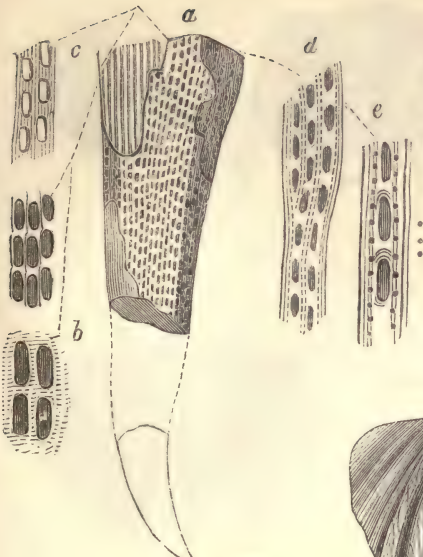


132

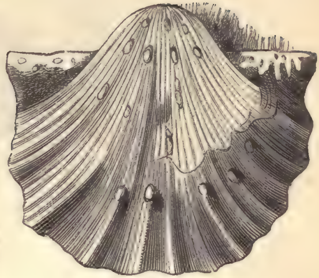


133

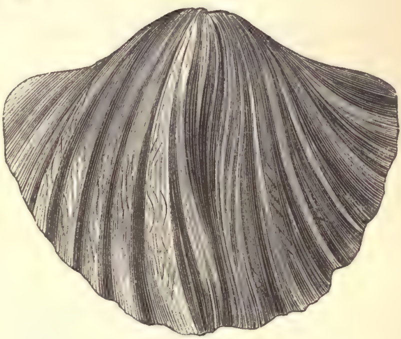
126 Platycrinus lævis.
127 Taxocrinus nobilis.
128 Taxocrinus egertoni.
128*a* To show the plates.
129 Actinocrinus polydactylus.
130 Pentremites ellipticus.
131 Phillipsia pustulata.
132 Limulus rotundatus.
133 Limulus anthrax.



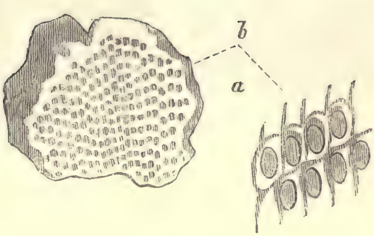
134



137



136



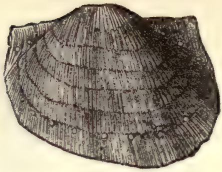
135

134 Fenestella membranacea.
134 *a b c d e* Magnified view.

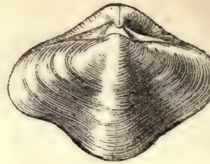
135 Ptilopora flustriformis.
135 *a* Magnified view.

136 Producta gigantea.
137 Producta pugilis.

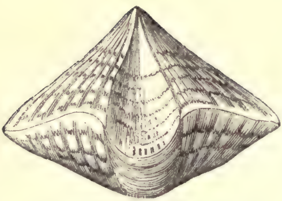
138



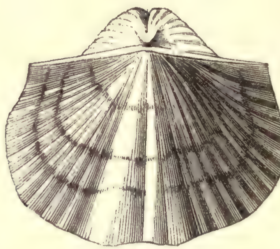
139



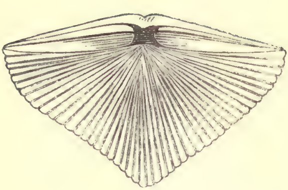
140



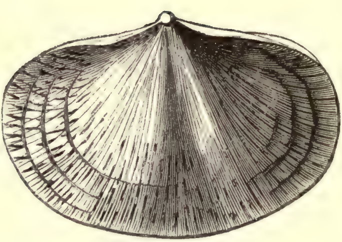
141



142



143



144

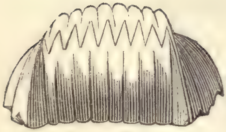
138 Producta punctata.
139 Producta martini.

140 Spirifera glabra.
141 Spirifera cuspidata.
142 Spirifera rotundata.

143 Spirifera striata.
144 Orthis resupinata.

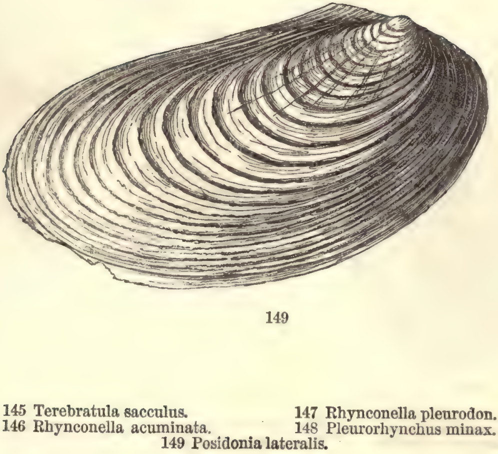
145

146



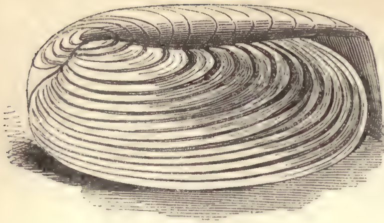
147

148



149

145 Terebratula sacculus.
146 Rhynconella acuminata.
147 Rhynconella pleurodon.
148 Pleurorhynchus minax.
149 Posidonia lateralis.

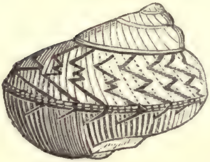


150

151

152

153



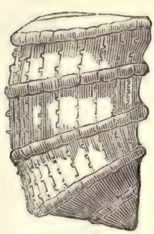
154

155

150 Edmondia sulcata.
151 Euomphalus pentangulatus.
152 Phanerotinus cristatus.
153 Natica ampliata.
154 Pleurotomaria flammigera.
155 Bellerophon hiulcus.

156

157

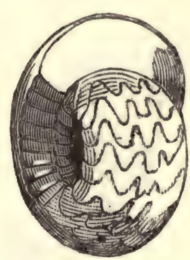


159

158

160

161

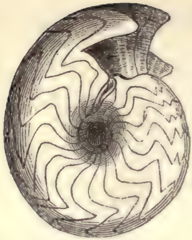


162

156 Bellerophon Urii.
157 Bellerophon costatus.

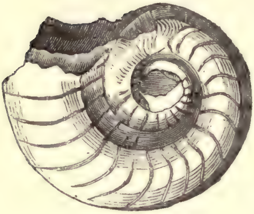
158 Orthoceras gesneri.
159 Orthoceras rugosum.
162 Goniatites listeri.

160 Orthoceras laterale.
161 Goniatites evolutus.



163

168



164

165

167

166

163 Goniatites striatus.
164 Nautilus sulcatulus.
165 Ctenacanthus tenuistriatus.
166 Holoptychius Hibberti.
167 Tooth of Megalichthys Hibberti.
168 Ichthyocoprolites.

PERMIAN SYSTEM.

It has been shown that the consolidated deposit of coal was subject to the effects of a very general disturbance of igneous agency from beneath, and that in this manner the whole arrangement of those deposits was altered, many parts of the bed of the sea being uplifted to form dry land. In the large but very irregular area left between these islands of carboniferous strata, the sea began to deposit limestones commonly charged with magnesia, sandstones remarkably coloured with red oxide of iron, and clays and marls of red, blue, and white colours; the whole series being, in general, far from rich in organic remains, seldom traversed by metallic veins, and not so much dislocated by faults as the older strata. Generally, its stratification is unconformed to that of the subjacent coal measures, on whose elevated edges, faults, and dikes, its planes rest level and undisturbed.

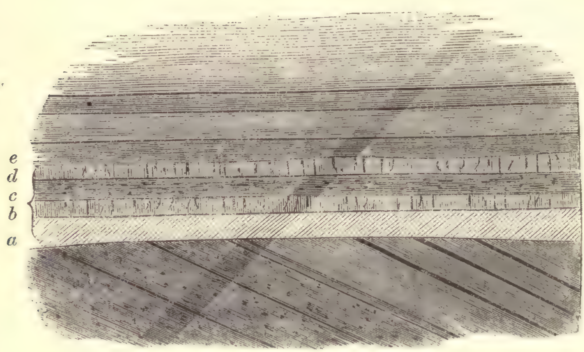
In the composition of this group we find traces of all the various operations of the sea; limestones crystallized, compact, brecciated, conglomerated, and earthy, full of magnesia, or containing carbonate of lime with little or no admixture, locally rich in organic remains, but frequently devoid of them; sandstones coloured red, blue, or white, in stripes and spots, fine grained, coarse grained, or full of innumerable pebbles, derived from primary rocks; clays and marls of many various hues; the limestones locally productive of the remains of saurians, fishes and shells, the sandstones and clays occasionally containing plants, but over large tracts wholly destitute of them. These organic remains are principally analogous to those of the carboniferous system, but partly to those which occur in the more recent deposits, and the whole series, though separated from both, offers by many resemblances besides its intermediate position, a natural transition from the one to the other.

In England, supposing all the limestones and red sediments mineralogically related to them to be present in one section, we should have, reposing unconformably on the coal strata, the following classification, beginning from above:—

MESOZOIC	4. Series of coloured marls…………………	Purple coloured marls below the lias. Alternations of red and bluish white marls, with layers and nodules of gypsum. Thin layers of argillo-calcareous stone. Red and bluish marls with gypsum and beds of rock salt.
	3. Variegated red and white sandstone……… (Poikilite of Conybeare.)	Red and white sandstone, mostly fine grained, and often impregnated with salt. Red conglomerate, full of pebbles of older rocks.

PALÆOZOIC	2. Magnesian limestone.	Red and white marls. Thin bedded compact limestone, with very little magnesia and few organic remains. Red and white marls and gypsum. White, yellow, or reddish magnesian limestone in thick beds, crystallized, compact, or earthy, often full of sparry cavities, and containing marine organic remains. Marl slate, in thin layers, occasionally enclosing fishes.
	1. Yellow or purple sand and sandstone and marl..................	An extremely variable series of sandstones, sands, and clays, of various colours, irregular thickness, and much local diversity of character. Plants like those of the coal measures.

In the former edition of this treatise, the composition of which was begun in 1830, all these strata were, in conformity with the views of Conybeare and Buckland, treated as one "system," called from its productiveness in salt the "saliferous," from its peroxidated aspect the "red sandstone," and from its variable tints the "poikilitic" system. The common characters by which it was so



169

The Permian strata superposed and unconformed to the coal measures (Yorkshire).

e Red marls. *d* Upper (non-magnesian) limestoue. *c* Gypseous red and pale marls. *b* Lower (magnesian) limestone. *a* Lower red sandstone (Rotheliegende).

united were mineral affinity, interlamination and mutual conformity of the strata, dissociation from the strata below and from those above. These characters still retain their force, but others have been placed in strong light, which render it desirable to divide this great red series

into two parts, the lower of which presents more of palæozoic, the upper more of mesozoic affinity.

In fact, the study of their organic remains has made great progress since, in the former edition, we remarked the superior resemblance of the fauna and flora of the lower part of the series of strata to the corresponding tribes of the subjacent coal measures, and the greater analogy in this respect between the upper parts and the oolitic series. "The general result of an examination of the conchifera of the saliferous system, is that in the upper strata a general analogy to the oolitic strata can be recognized by the trigoniæ, plagiostomata, ostrææ, &c., and in their productæ and spiriferæ the lower strata as distinctly claim affinity with the carboniferous limestone."*

The view thus announced became more clear with time. The consequences of it on the classifications of English strata were expressed cautiously in 1837,† and positively affirmed in 1840‡ and 1841§ as part of a general scheme. After some hesitation,|| Sir R. Murchison's investigations satisfied him of the truth of this view: and while registering the results of his great survey of Russia, founded, in harmony with it, the "Permian system,"¶ now universally accepted as the uppermost member of that great Palæozoic series, which owes to the same hand many of its foundation stones. By this consent of geologists to an important change of classification, they have in fact affirmed as a principle, that it is by groups of associated organic forms, indicating *life periods*, that the chronology of the ancient world is to be measured and arranged. The collective character of the Permian system, then, is in its organic remains; the plants which occur in its lower red sandstone are analogous to, if not identical with, those of the coal strata; the shells and radiaria and bryozoa of the calcareous beds resemble those of the mountain limestone. But when, as often, indeed frequently, happens, these fossils are few and rarely to be seen, it is difficult to separate the sandstones of the Permian from those of the Triassic group—a difficulty which is even now meeting the government geological survey on the borders of Derbyshire and Cheshire, and in the interior of Warwickshire. This difficulty will probably be overcome by the untiring zeal of the excellent field geologists who have been trained on this survey. But it deserves to be pointed out as an example of what frequently occurs —an example of some want of exact contemporaneity in the marked changes of mineral deposits, and the marked changes of organic life. We have already seen, in the case of the transition from Silurian to old red deposits, that bands of this red deposit are interposed among

* Encyclop. Metrop. Geology, ch. ii. p. 615, *et seq*, published 1833.

† Treatise on Geology—Cabinet Cyclop., vol. i., p. 189. See also Brown's Lethæa Geol. of the same year.

‡ Penny Cyclop.—"Palæozoic."

§ Palæozoic Fossils of Devon and Cornwall.

|| Address to the Geol. Soc., 1842.

¶ Geological Proceedings, 1842; and Geology of Russia, 1844.

the groups of upper Silurian life. In the case now before us, bands of red and blue trias-like sandstones and clays, with gypsum, are interposed among the strata which yield the Permian forms of life. In each case the change in mineral sediments is manifested in a given area of the ancient sea, *before*, in that sea, the great and characteristic changes of marine life occurred. But in the still earlier case noticed on the western flank of the Malverns, we found sediments of a lower Silurian type poured into a sea rich in forms of the upper Silurian age—a return of the old sediments to a basin which it seemed they had deserted. It is, however, merely a want of *exact* contemporaneity which is remarked; on a great scale, it cannot be doubted that there is some real mutual dependence, some real coincidence—not indeed of *epochs*, but certainly of *periods*—between the changes of physical condition and the revolutions of organic nature.

Range of the Permian System in England.

Of the beds included in this arrangement, the calcareous strata are perhaps the least extensive, yet, as usually happens, they are most regular and continuous in their ranges, and most consistent in characters, and afford the best data for the classification of the others. By looking at a geological map of England, the extent of the range of magnesian limestone may be observed from the north side of the Tyne uninterruptedly to the Tees, between which river and a place called Thornton Watlas, it is known only in a few points, though probably it exists continuously beneath the superficial accumulations of gravel. From this point to Bilborough, near Nottingham, its course is uninterrupted.

Below it, in a narrow irregularly parallel tract on the west, reposing on all the members of the coal formation indiscriminately, runs the lower series of sandstones and marls; above on the east, through Yorkshire and Nottinghamshire, ranges the conglomerate red sandstone, and upon this lies, through Durham, Yorkshire, and Nottinghamshire, the Mesozoic series of upper coloured marls and gypsum.

Cumbrian District.—On the western side of the summit ridge of the north of England, the vale of the Eden is filled by the new red sandstone formation, consisting principally of coarse or fine grained red sandstone, and red marl above, with, in one place, a remarkable series of conglomerate, or rather brecciated beds at the bottom, and in another a distinct deposit of magnesian limestone. The former is seen at Kirkby Stephen, in the angle between two lines of dislocation, and affords a very instructive point of comparison with an analogous deposit in Somersetshire, known by the name of millstone. It has a

basis of red sandstone almost entirely filled with angular fragments of the neighbouring limestone strata; it is disposed in vast unequal beds, with large distant joints almost invariably ranging north and south, lies with a dip to the east between the lines of two dislocations of the carboniferous limestones, to the violence accompanying which its own production was probably owing. It is not in general magnesian, yet some yellow beds contain that substance, and thus we are led to refer its production to the date of the lower parts of the magnesian limestone.

No further trace of beds analogous to the magnesian series of Yorkshire and Durham occurs, in the westward extension of the new red sandstone group, round the Cumbrian mountains, till we reach Whitehaven, where magnesian limestone and conglomerate, lying in red sandstone, are sunk through in the coal pits, and seen in the high cliffs against the sea towards St. Bee's Head. From Professor Sedgwick's examination of this district we learn that the section here presented is more closely similar to that of Yorkshire than was previously supposed, and that the following groups are uniformly laid upon the coal system:—

3.	Variegated red sandstone of St. Bee's Head.
2. Magnesian limestone.	Red marl and gypsum. Magnesian limestone, sometimes replaced by or alternating with magnesian conglomerate. Magnesian conglomerates, analogous to those in the vale of Eden and various parts of Yorkshire.
1.	Coarse reddish sandstone of great thickness on the whole unconformed to the coal measures, but also in part unconformed to the rocks above, which lie in its hollows.

In their northward extension beyond the Solway Frith to Dumfriesshire and Galloway, the red sandstone strata do not exhibit any traces of magnesian limestone.

Midland Counties.—Beyond the southern termination of that rock, near Nottingham, the variegated red sandstones and coloured marls spread themselves over the whole area between Leicester, Warwick, and Worcester, on the one side, and Shrewsbury, Chester, Liverpool, on the other, and extend northwards to Manchester, Leek, and Ashbourn. Yet in all this immense area, except near Manchester, we nowhere find any deposits strictly analogous to the magnesian limestone. The South Lancashire coal field is bordered in places by magnesian limestone and red marls, containing axinus and other Permian shells. In this neighbourhood also, as at Worsley collieries, we appear to recognize the lower red sandstone of Yorkshire, in several places overlying the coal beds, and it is probable that further examination may extend these points of agreement. Near Shrewsbury, likewise, the coal strata are succeeded by what appears to correspond

to the lower red sandstone, and upon this lies an often trappoid or magnesian conglomerate. The South Staffordshire field certainly, the North Staffordshire probably, is margined by Permian conglomerate.

Continuing our survey down the Vale of Severn, we find reason to reckon the trappoid conglomerate which overlies the coal of Abberley, and abuts against the syenite of Malvern as of the same Palæozoic age, as suggested in our survey of that district (1842 *et seq*).*

South of England.—South of the Malvern hills, the variegated sandstones and marls, the latter predominating, pass down the Vale of the Severn, fill up the winding intervals of the dislocated carboniferous limestone, partly cover the coal basins of Somersetshire, spread in the vales of the Parret and the Exe, and reach the sea at Exmouth.

The only parts of this extensive range where magnesian rocks appear distinctly, is amongst the limestone and coal tracts of Somersetshire, and South Gloucestershire. Along the sides of Mendip magnesian conglomerates of considerable extent separate the limestone from the red sandstone, and produce the ores of zinc; a similar deposit, in similar relation to the older limestone, appears along the Avon below Clifton, and at Radstock and other places it is pierced in the collieries, at or near the bottom of the new red sandstone, and receives the name of millstone. Conglomerates of a very singular, even porphyritic, character occur near Exeter, in the lower part of the variegated sandstone and marls; and from a general review of the whole subject, Professor Sedgwick classes the conglomerates of Exeter, Somersetshire, and Shropshire, with the lower or conglomerate portion of the magnesian limestone of the north of England. The red conglomerate of Exeter is by De la Beche ranked with the rothetodteliegende.

From this view of the subject, which is usually adopted, it would appear that the difference of the Permian system in different parts of England, arises rather from the limited continuity of the beds, than from any great variation in their quality or relations. The series is perhaps nowhere more complete than in the interval between the Wharfe and the Dun, yet even here several beds are deficient. The marl slate and conglomerate limestones are better studied in Durham, the upper limestone in Yorkshire and Derbyshire; the lower red has the largest range, and is in fact, in England, accompanied by magnesian conglomerate, the most extensively distributed deposit.

Ireland.—In Ireland the Permian beds are very limited; but about the Lough of Belfast they are well exhibited, magnesiferous and calcareous, with a few Permian fossils.

* Memoirs of Geol. Survey, vol. ii., part 1. Ramsay (1854) has suggested that the singular phenomena noticed in this rock may be best met by supposing its masses to have been transfixed by ice.

Permian System of Europe.

General View.—We are now at liberty to consider the characters of the Permian system as they appear in the other parts of Europe, which have been accurately examined by geologists. This comparison is much facilitated by the mutual understanding now so general between English and foreign observers, and the subject is made familiar to our countrymen by the published inferences of Sedgwick and Murchison. In the greater part of the region on either side of the Rhine, beds corresponding to the magnesian limestone of England are entirely unknown. It is chiefly along the line of the south-western face of the Thuringerwald, prolonged to the north-west as far as Münden, in the drainage of the Weser, along the southern and eastern borders of the Harz, and on the north-west side of the slate formation connected with the Erzgebirge, in the drainage of the Elster, that the zechstein and rauchwacke represent on a greater scale the yellow magnesian and upper laminated limestone of the north of England.

They have been thus placed in apposition by King*—

Thuringian Permians.	North of England Permians.
Stinkstein.	Crystalline and other limestone.
Rauchwacke.	Brecciated limestone.
Dolomit.	Fossiliferous limestone.
Zechstein.	Compact limestone.
Mergel-schiefer or Kupfer Schiefer.	Marl slate.
Todte-liegende.	Lower sandstone.

This table, however, is deficient of the upper members.

In the great Permian region of Russia, Murchison has had ample opportunity of studying this remarkable group of strata. It is there apparently, or for the most part, conformable to the older carboniferous system; contains gypsum, salt, and copper; consists of grit, sandstones, marls, conglomerates, and limestones; and contains one group of animal and vegetable life, the past and feeble, but still real representative of palæozoic periods. Amidst the many varieties of sequence amongst the redder rocks, it appears to be recognized that "limestones, often interstratified with much gypsum, prevail toward the base of the Russian deposit.†" The forms of Permian life extend upwards above these calcareous portions, so that in completing the system, some part or the whole of the superincumbent red sandstones or conglomerates may properly be included.

This inference has a bearing on Germany and England; in both countries the red sandstones and conglomerates above the magnesian limestones may perhaps be divisible—indeed this has been already

* Permian Fossils, 1850.

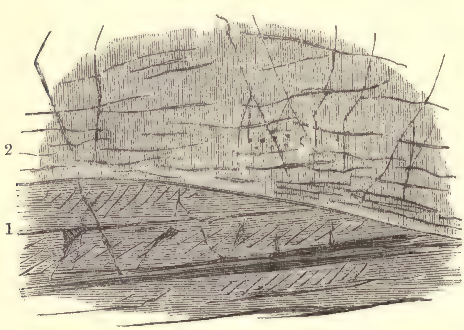
† Murchison, Siluria, p. 295.

done by Murchison—into upper Bunter, belonging to mesozoic, and lower Bunter, containing sometimes plants of the palæozoic age. This adds another illustration of the caution required in employing and weighing the relative value of mineral and organic analogies.

Remarks on certain Members of the Permian System in England.

Variegated Sandstones and Clays.—It will be useful to describe more particularly the general characters of the terrace of magnesian limestone, and its associated strata, which occupies so remarkable a range in the north of England. The table already given will explain the relation of the several members of this group, and we shall at present confine our attention to the calcareous portions. The most ample details on every point will be found in Professor Sedgwick's paper in the *Geological Transactions.*

Marl Slates.—Immediately above the lower red sandstone in the excavation for the Stockton Railroad, were found in ascending order, (1.) thirty feet of light-coloured siliceous sandstone in thin beds, alternating at the top with blue calcareous slate; (2.) nine feet of yellow calcareous shale and marl slate, some of the beds incoherent and sandy. In this marl slate, about two feet above the sandstone, were found many impressions of vegetables (ferns) and fishes of the genus palæothrissum. The higher and more compact beds also contained productæ, spiriferæ, and terebratulæ. The shales or marls of this series are sometimes highly bituminous. (3.) Twenty feet of thin calcareous beds with marly partings.



170* Section at Knaresborough.

These slaty marls and limestones have a very irregular extent even in Durham, and are imperfectly traceable in Yorkshire. They are perhaps best exhibited about Kippax, (very thin), at Garforth Cliff, on the road from Leeds to Selby, where they are full of axinus obscurus, and contain a spinose species of monotis. Deposits somewhat analogous are described by Professor Sedgwick near Bolsover. Little or no magnesia is found in this part of the series.

170* (2), Yellow magnesian limestone resting on worn surface of (1) the Rotheliegende.

Yellow Magnesian Limestone.—The yellow magnesian limestone, whose extreme thickness between the Aire and the Dun certainly exceeds 300 feet, exhibits the most astonishing diversity of mechanical structure, without a corresponding diversity of chemical composition or definite geological divisions. Several varieties yield upon analysis carbonate of magnesia and carbonate of lime, in the simple proportion of atom to atom, (for example, the building stone of Huddleston and Warmsworth,) and in almost all the proportion of magnesia is large. In the southern part of its range, the structure of the rock is generally crystalline, and the crystals (rhomboids) being small, and often tinged of a reddish or yellow colour, the whole might be easily mistaken for sandstone. On the contrary, in the northern part of its range, a concretionary structure is often observed, and thus globular masses of carbonate of lime of various magnitude compose beds of stone or lie loose amongst a quantity of yellow, powdery, calcareo-magnesian carbonate. But the variety of the appearances presented by this kind of structure is so great, that on entering a quarry near Sunderland we are struck by the organic aspect of the whole escarpment, as if it had been a reef of coral. On the coast of Durham beds of this structure appear associated with masses of brecciated limestone, but very irregularly, and under circumstances not easily explained, without supposing the deposits to have been subject to repeated local and violent disturbance.

Certain beds of this rock in Yorkshire and Derbyshire are very compact; in Durham some are composed of numerous thin, incoherent layers. In several places North of the Dun and specially near Tadcaster largely oolitic portions are distinguishable.

But by far the most plentiful of all the varieties of this changeable rock, especially to the north of the river Wharfe, is a loose earthy mass of indistinct beds, with hollow geodes of crystallized carbonate of lime, and numerous veins or strings of the same substance, dividing the rock into irregular cells, and helping to hold it together. This character of crystallized cavities and sparry strings is very common to the whole formation, and we occasionally find oxydulated iron, sulphate of strontian, or sulphate of barytes in these cavities. In the quarries at Weldon occur layers of siliceous nodules, analogous to the chert lumps in limestone, oolite, and green sand, and to the flints in chalk. Veins of sulphate of barytes cross the magnesian limestone in several places near Ferrybridge, and near Wetherby. Galena occurs in it at Mansfield and at Warmsworth near Doncaster in small veins, and in other places in detached crystals, as does also sulphuret of zinc; carbonate of copper lines some joints of the rock at Newton Kyme near Tadcaster, at Warmsworth, and at Farnham near Knaresborough; muriate of soda has been obtained by Mr. Holmes from the red beds of Mansfield.

Organic remains of fenestellæ, crinoidea, brachiopodous bivalves, and other shells of mollusca, occur in this rock, in by far the greatest abundance near Sunderland in Durham; they are much less plentiful in the upper parts of the rock in Yorkshire between the Dun and the Wharfe; and only a few species obscurely show themselves in Derbyshire and Nottinghamshire. There is a great analogy between the organic remains in the magnesian limestone of Durham, and those of the older carboniferous limestone, and it especially deserves attention that in this rock the genus producta is seen for the last time as we ascend the series of strata, while no ammonite has yet been found in it.

Above the yellow magnesian limestone is a series of gypseous red and white marls, fifty feet thick or more, and this is surmounted by the upper laminated limestone.

Upper Laminated Limestone.—This rock is not coextensive with the yellow limestone, but has a more limited range, scarcely extending beyond the boundaries of Yorkshire. It is most fully developed in the tract between Tadcaster and Tickhill, and may be examined advantageously at Brotherton and Knottingley, where enormous quantities of it are burned annually to lime for agricultural purposes.

It here reaches to about fifteen yards in thickness, and is composed of a vast number of small irregular layers, separated more or less by partings of marl, and obscurely united into uneven and often undulated beds. The stone is nearly devoid of magnesia, its substance is usually compact, so as even to fit it imperfectly for the purpose of lithography; it is remarkably full of dry cracks, which have dendritical faces, and small cavities lined with crystallized carbonate of lime appear in the thicker layers. The thickness of the layers increases suddenly, or the beds become more consolidated toward the bottom, and in this part the crystallized cavities become more numerous and larger, the stone is less compact, holds more magnesia, and is of no value for lime. The prevalent colour of the stone is a smoke gray, which is often disposed in spots or stripes, and the separating marls are generally light gray, but often purplish, and farther south reddish.

Organic remains occur but very rarely, and in the lower beds only. They are very imperfect in general, but appear to be of the same species as others from the yellow limestones of the same vicinity.

Farther north, at Nosterfield, these beds change their aspect considerably, so as to resemble closely some kinds of carboniferous limestone, a resemblance increased by the presence of productæ, and the occurrence of galena. About Doncaster the rock assumes a redder aspect, and contains some beds full of magnesia. It is then said to be a *hot lime*, and like the product of the yellow limestone, is injurious if laid on the land in large quantity.

Prevalence of Magnesia.—The circumstances which permitted the accumulation of the magnesian carbonates of lime are in great measure unknown to us. That they were originally deposited in the same chemical condition as we now see them, without the subsequent aid of any igneous operations, is perfectly evident. It has been imagined because certain beds of the carboniferous limestone contain a large proportion of magnesia, that the one is derived from the ruins of the other. But, as Professor Sedgwick observes in discussing this subject, (*Geological Transactions*,) all the magnesian beds in the carboniferous limestone would be quite insufficient for the purpose, and the *crystalline character* of the Mansfield and other varieties of magnesian limestone clearly negatives this mechanical solution. Beds rich in magnesia alternate with others devoid of that substance, the same beds are in one tract magnesian, in another yield pure lime, and in general we must be content to shelter our ignorance under the statement that from some unknown cause the waters of the sea were then decomposed in such a way as to permit very generally the precipitation of united magnesian and calcareous carbonates—the possible circumstances of which must be entrusted to the examination of the chemist.*

GENERA OF ORGANIC REMAINS IN THE PERMIAN SYSTEM, AS GIVEN BY KING.†

PLANTS.

Chondrites?	1	Near Manchester.
Polysiphonia?	1	Durham.
Caulerpa?	1	Durham.
Neuropteris,	1	Durham.
Lepidodendron,	1	Durham.
Calamites,	1	Durham.
Sigillaria?	1	Durham.

AMORPHOZOA.

Scyphia,	1	Durham.
Mammillopora,	1	Durham.
Tragos,	2	Durham.
Bothroconis,	1	Durham.

FORAMINIFERA.

Dentalina,	3	Northumberland.
Textularia,	2	Northumberland.
Spirilina,	1	Durham.

ZOOPHYTA.

Calophyllum,	1	Durham.
Petraia,	1	Durham.
Calamopora,	1	Durham, Northumberland.

* Forchhammer in Reports of Brit. Assoc., 1849. Johnston in Reports of Brit. Assoc., 1853.
† Monograph of Permian Fossils, 1849.

Stenopora,	1	Durham, Northumberland.
Alveolites,	1	Durham.
Aulopora,	1	Durham.

ECHINODERMATA.

Cyathocrinus,	1	Durham, Northumberland.
Archæocidaris,	1	Durham.

ANNELIDA.

Spirorbis,	2	Durham, Northumberland.
Filograna,	1	Northumberland, Yorkshire.
Vermilia,	1	Durham.
Serpula,	1	Durham.

CRUSTACEA.

Cythere,	10	Durham, Northumberland.
Dithyrocaris,	1	Northumberland.

BRYOZOA.

Fenestella,	1	Durham, Northumberland.
Synocladia,	1	Durham, Northumberland.
Phyllopora,	1	Durham.
Thamniscus,	1	Durham, Northumberland.
Acanthocladia,	1	Durham, Northumberland.

BRACHIOPODA.

Lingula,	1	Durham.
Discina,	1	Durham.
Producta,	2	Durham.
Strophalosia,	4	Durham, Northumberland, Yorkshire.
Streptorhynchus,	1	Durham, Northumberland.
Camerophoria,	3	Durham, Northumberland.
Trigonotreta,	6	Durham, Northumberland.
Martinia,	2	Durham, Northumberland.
Cleiothyris	1	Durham, Northumberland.
Epithyris,	2	Durham, Yorkshire, Northumberland.

MONOMYARIA.

Pecten,	1	Durham, Northumberland.
Lima,	1	Durham.
Monotis,	3	Durham, Northumberland, Yorkshire.

DIMYARIA.

Mytilus,	2	Yorkshire, Durham, Northumberland.
Edmondia,	1	Durham.
Bakevillia,	5	Durham, Northumberland, Manchester.
Byssoarca,	3	Durham, Yorkshire, Northumberland.
Nucula,	1	Durham.
Leda,	1	Durham, Northumberland.
Solemya,	2	Durham.
Cardiomorpha,	1	Durham, Northumberland.
Pleurophorus,	1	Durham, Northumberland, Manchester.

Schizodus,	4	Yorkshire, Manchester, Durham, Northumberland.
Astarte,	2	Durham, Northumberland.
Allorisma,	1	Durham, Northumberland.
Psammobia,	1	Durham.
GASTEROPODA.		
Chiton,	1	Durham.
Turbo,	5	Yorkshire, Manchester.
Rissoa,	3	Durham, Manchester.
Loxonema,	3	Durham, Manchester.
Macrocheilus,	1	Durham.
Euomphalus,	1	Durham.
Natica,	1	Durham.
Pleurotomaria,	4	Durham.
Dentalium,	1	Yorkshire.
CEPHALOPODA.		
Nautilus,	2	Durham.
PISCES.		
Gyracanthus,	1	Durham.
Gyropristis,	1	Near Belfast.
Palæoniscus,	6	Durham, Northumberland, Dungannon.
Platysomus,	2	Durham, Northumberland.
Acrolepis,	1	Durham, Northumberland.
Pygopterus,	3	Durham, Northumberland.
Coelacanthus,	2	Durham.
REPTILIA.		
Palæosaurus,	2	Near Bristol.
Thecodontosaurus,	1	Near Bristol.

NOTE.—These genera occur in a conglomerate, resting unconformably on the mountain limestone near Bristol, which is not *ascertained* to belong to the Permian age.

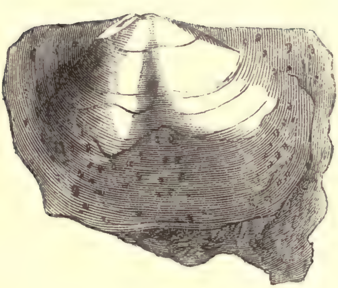
Professor King's summary of the Permian fossils of England and Ireland gives us the following results, expressed in the same terms as those employed for the other palæozoic strata.

		Proportion 1,000.
Plants,	7	49
Amorphozoa,	5	35
Foraminifera,	6	42
Zoophyta,	6	42
Echinodermata,	2	14
Annelida,	5	35
Crustacea,	12	84
Bryozoa,	5	35
Brachiopoda,	23	161
Monomyaria,	5	35
Dimyaria,	25	175*
Gasteropoda,	21	147
Cephalopoda,	2	14
Pisces,	16	112
Reptilia,	3	21
	143	1001

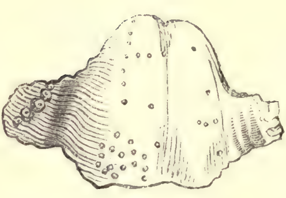
Still brachiopoda and gasteropoda abound, but dimyaria have sprung up to fully rival them; cephalopoda are reduced to a small number, and crustacea are relatively important, the small groups of entomostraca having experienced diligent examination by Jones, who has also scrutinized the foraminifera.

PERMIAN FOSSILS.

171

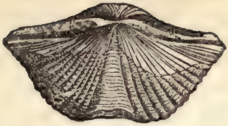


172



173

171 Synocladia virgulacea. 172 Producta horrida. 173 Different aspect of P. horrida.

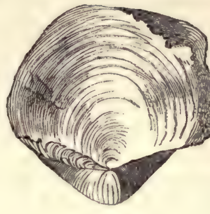


174

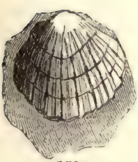
175

176

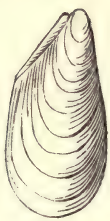
178



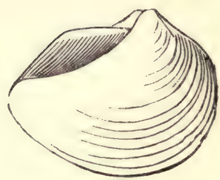
177



179

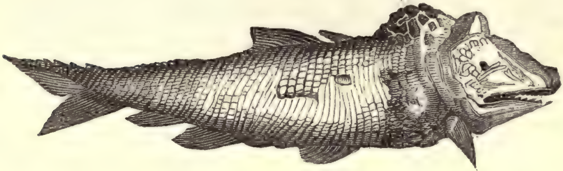


180



181

182



183

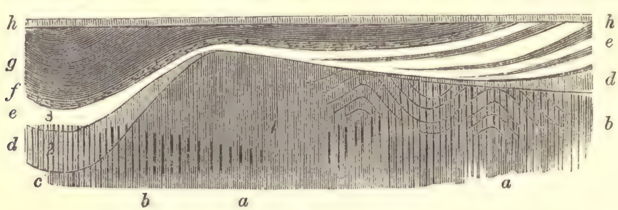
174 Spirifera undulata.
175 Terebratula globulina.
176 Terebratula elongata.
177 Monotis speluncaria.
178 Different aspects of.
179 Monotis radialis.
180 Mytilus squamosus.
181 Axinus obscurus.
182 Pleurophorus costatus (cast).
183 Palæoniscus comptus.

General Conclusions concerning Primary Strata.

The general system of operations disclosed to us by an examination of the primary strata, presents the following leading points.

A General Basis of Igneous Rocks.—The lowest rocks which we can trace, those upon which the vast accumulations of stratified rocks rest, are such as from all their characters appear to have been produced by igneous agency. These granitic, hypersthenic, &c. rocks are crystallized like the products of fire, composed of minerals like those observed to be generated by heat, and combined in a very similar manner. They show no action of water, either chemical or mechanical, nor contain the reliquiæ of living beings. The almost universal extent of these rocks, combined with the abundance of their disintegrated materials in the older strata, proves the great extent of the igneous agency developed in the earliest eras definable by geologists.

Influence of Heat on Primary Strata.—The same inference of a pervading and powerful development of heat in those early periods, may be safely drawn from a consideration of the generally high degree of solidification among the earliest primary strata, and their frequent though imperfect crystallization. There is little doubt, or rather the geologist of sufficient observation considers it a matter of certainty, that the crystallization of primary limestone, the conglutination of gneiss and quartz rocks, and the rhomboidal fissures of slate, are due to the same cause as the conversion of chalk into such limestone, the induration and semifusion of sandstones, and the prismatizing of shale by the action of basalt, and by the heat of a furnace; and it is certain from various facts that these characters were in many cases acquired by the primary strata before the formation of any member of the secondary rocks. We give in fig. 184 a view of the distribution of *slaty cleavage* in these rocks, connected



184

Section of Palæozoic systems as effected by cleavage.

h Permian system unconformed to the strata below. *g* Coal measures. *f* Millstone grit. *e* Carboniferous limestone, cleavage entering its lowest members in South Wales, North Devon, and south of Ireland—not in the north of England. *d* Old Red—with cleavage in the south, not in the north of England. *c* Upper Silurian, with cleavage in South Wales, but not in the Midland or Northern counties. *b* Lower Silurian, with cleavage both in the south and the north. *a* Cambrian, with cleavage generally.

with a general section from south to north, and propose in a later page to consider the probable explanation of the great diversity in this respect, which the section shows, for in South Wales cleavage affects the strata up to the lower mountain limestone series, but in the north of England does not go through the whole of the silurians.

Organic Remains Absent from the Lowest Primary Strata.—Possibly this great and continuous heat beneath the ancient beds of the ocean, may be admitted as a reason for the paucity of animal and vegetable life during the earliest primary period. The fact, however, is that among the older of the primary strata the remains of plants and animals do not occur; and it is probable that the living wonders of nature were not then in existence. It is, indeed, maintained that such remains would be wholly destroyed in the rocks by the operation of such a heat, and this opinion may be supported by many strong analogies. But as marine organic remains do occur, though rarely, in the midst of the Cambrian group, (Llanberris,) and become numerous in and near the calcareous bands of the upper portion of that series, it appears safer to admit that the heat, or some other unknown condition of this early period, was unfavourable to organic existence in the sea. It seems almost demonstrated that at this period there was very little dry land raised to the surface of the globe; for all the present continents were certainly uplifted at subsequent and successive epochs, and therefore land plants could not be abundant.

Become Frequent in the Upper.—But in proportion as the igneous agency found vent, in the same ratio as the mountains were uplifted, we find the organic reliquiæ of the sea and of the land embedded in greater abundance.

Objections to this Hypothesis Considered.—It may be objected by those who see in the ancient effects of nature nothing but the result of the present measure of natural operations, that three-fourths of the globe are now covered by water, and that the depression of one large tract may have corresponded to the elevation of a smaller; and that remains of plants and animals may occur in the submerged portion of the crust of the earth, of higher antiquity than any of our elevated strata. This *may be true;* and it may also be true, as some persons suppose, that stratified rocks full of organic remains occur beneath the granitic floor; but as neither of these hypotheses can be proved or even examined, they must remain as *mere speculation.* Nor is it a *probable* speculation. For certainly the continually diminishing number of species, genera, families, and even classes of animals, as we retrace the series of Palæozoic creations, leads us naturally and forcibly to the conviction that we are approaching at once to the earliest traces of life, as well as to the earliest traces of watery action. We cannot avoid the conclusion that the earth has

passed through great physical changes, and that the *present measures* of physical effect are not directly applicable to the epochs of earlier nature. From such *differentials* we cannot obtain the integrals of the periods which have gone by.

General Ground of Argument.—In maintaining the *uniform character* of the natural terraqueous agencies, and the *constancy of their mode of action,* all philosophers are agreed; but, as in every other problem submitted to investigation, experiment, or observation, the *conditions* are to be determined before the rate and measure of geological results can be expressed on a scale of magnitude or number. In a science founded on observation, these conditions cannot be known beforehand, they are the very objects of which we are in quest, and our only mode of approaching them is by analyzing the effects which have been produced by the known laws of nature, operating under these, at first unknown, conditions. What is the object of an experimental investigation, in which first the law is given, and next the conditions are assumed, the result of their combined operation having been previously defined?

Greater Effects of Heat in the Older Epochs.—A history of the successive revolutions in the state of the globe must indeed be founded on a survey of the chemical, mechanical, and vital phenomena, now produced by the atmosphere, rivers, the sea, and volcanoes; and all conclusions concerning the intensity, duration, and extent of igneous and aqueous agencies, in past geological periods, must proceed upon an examination and estimate of these agencies in the existing periods; but the ratio of their effects at different periods is to be determined by evidence, not assumed by conjecture.

The results of examination of the organic remains in the several strata, and of the character and condition of these strata, according to their relative antiquity, leave no doubt of the vastly greater and more general influence which, in the older geological periods, the *proper* heat of the earth had upon all the operations of nature in the sea and on the land, an influence far more equable as well as more intense than that exerted by the solar rays, independent of the seasons, and coextensive with the globe.

Surely, then, under these peculiar conditions, the laws of nature which are concerned in the operation, themselves invariable, must have operated on a greater scale, and perhaps with higher intensity, than that which now characterizes their effects.

All the results depending directly on the quantity of communicated heat,—as, for instance, most of the phenomena connected with the decomposition, reconstruction, and consolidation of rocks,—must have been vastly increased in amount, and proportioned in extent to the universal diffusion of heat; while the arrangements of organic life which we know to be *adjusted to a certain limited range* of temperature,

must have been proportionately affected. Until the mean temperature of the sea was reduced to a certain standard, the physical conditions to which organic life is restricted on our globe were not established; but during these periods the inorganic forces of nature must have been especially active, and on a very great scale. Hence the vast thickness, the great degree of consolidation, the crystalline character, the almost universal extent of the primary strata; hence the rarity of organic remains, until, by the accumulation of considerable thicknesses of nonconducting earthy materials upon the bed of the ocean, the communication of heat from the interior of the globe was retarded, so as to be counterbalanced by that constant radiation from its surface, which is one of the conditions whereto the organization of plants and animals is adjusted.

CHAPTER IX.

LOWER MESOZOIC STRATA.

Range and Physical Features.—We now enter, by an easy mineral gradation from the Permian rocks, the next great division of the strata—the Mesozoic series, which includes a large part of the group formerly called "Secondary." In the British islands, this mass of peroxidated sandstones and clays shows itself a little on the north-east of Ireland, by the Lough of Belfast, on the coast of Antrim, and west of Lough Neagh, unconformed to the previously dislocated coal, limestone, and other older strata. The Marquis of Downshire, searching for coal beneath it and the Permian strata, sunk near Carrickfergus through the new Red, and found it, as in Cheshire, productive of rock salt. It is in some places covered by green sand, but liassic strata appear on the Antrim coast.

In Scotland, Red sandstones overlie the coal of Arran, and were thought by Murchison and Sedgwick to be of this age. More surely the sandstones of Dumfriesshire, on some of which, at Lochmaben, are the footprints of vertebrata, belong to the lower part of the Trias, and are continuous with the much broader area of new Red sandstones and marls, which fill the Vale of Eden, in Cumberland, sweep in a crescent round the coal and limestone of Allenby, Hesket, Lowther, and Shap, and lie on the depressed side of the great Craven fault, under the great escarpment of Cross Fell. On the opposite

side of the Cumbrian mountains, from St. Bee's Head by Ravenglass and Dalton in Furness, this series of beds recovers its course, and, interrupted by the Bay of Morecambe, reappears in the low part of Lancashire, by Poulton, Preston, Ormskirk, and Liverpool. Here it expands so as to occupy a large breadth in the midland counties, from Chester and Shrewsbury on the west, to Manchester, Congleton, Newcastle-under-Lyne, Cheadle, Ashbourn, and Nottingham, on the east. From Nottingham a long continuous belt of these red rocks runs northward, resting nearly or quite in conformity on the Permian, which overlies unconformably the coal, millstone grit, and mountain limestone. This band, including the Vale of the Trent, and the vales of York and Mowbray, expires in the broad estuary of the Tees. Resuming our survey at Nottingham, we find the great area between that town, Leicester, Coventry, Warwick, Worcester, and Shrewsbury, filled with new Red sandstone and marls, except where the subjacent coal measures stand up through them, nearly as they did stand up in the sea which receive the red sediments. (See p. 191.)

From Worcester southwards, the Severn Vale is chiefly in new Red, which, after winding round many sinuosities of the coal measures about Bristol, and the mountain limestone of Mendip, spreads in the rich vales of Taunton and Exeter, and occupies a great breadth of sea cliff in the mouths of the Teign, Exe, Sid, and Axe. Expanding from the main mass, patches of new Red appear in the interior of Devonshire, in Barnstaple Bay; in the cliffs of West Somerset and North Devon; on the south side of the Welsh coal field about Bridgend; in the Vale of Clwyd and Anglesea.

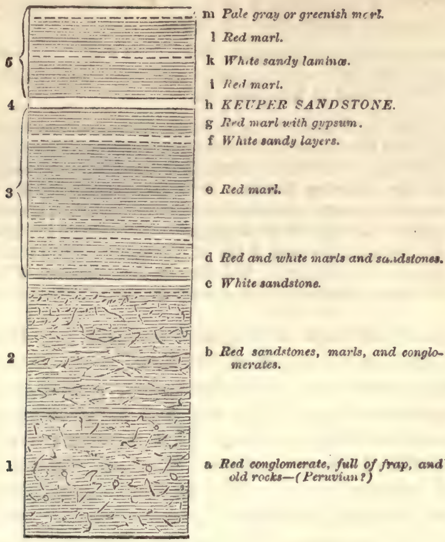
In this long range, and in this large area, the new Red sandstone is everywhere marked by comparatively gentle features, easily swelling undulations, relieved here and there by picturesque cliffs of sandstone, over a pleasant river, such as the Mersey above Stockport, the Dee about Chester, the Don about Ashbourn, the Avon at Warwick. In no part of the island does the sandstone of this series make hills more than 1,000 feet above the sea, the more conspicuous in feature being the Hawkstone ridges of Cheshire and Nottingham Castle; if, indeed, these be not really composed of Permian rocks, as the cliffs about Warwick have been conjectured to be. The marly parts of the new Red are generally fertile, the sandy and pebbly parts less so, or even barren, as in some parts of Sherwood Forest.

Types of the Series.—Having inspected almost every part of this Poikilitic series, it appears to us that the best general type is to be found in the Vale of the Severn, where between Tewkesbury and Newent, in a breadth of 10 miles, we have the subjoined general series, with a total thickness of about 450 yards.*

* Memoirs of the Geological Survey of Great Britain, vol. ii., part 1.

In a vertical section the beds may be thus separated :—

185



The several beds may be thus described in the order of their successive depositions :—

m Pale greenish marls, differing only by the colour from the red series below. Above is the regular series of bone beds and lias.

l Red marls.

k Thin laminæ and white sandstone, and greenish marls. Here not seldom are cubical sandstone casts, in cavities once occupied, it is probable, by rock salt crystals.

i Red marls.

h Sandstone, white, yellowish, or brownish, generally full of oblique lamination, indicating shallow water and currents, with fish teeth and bone, bits of coal, stems of plants. Alternating with these are pale blue shales, much resembling those of the lias, with small bivalve shells. This fossiliferous series makes a traceable band in the Red series; its protoxidated sediments being derived from another direction—possibly from the quarter which afterwards yielded the lias.

g Red marls, with gypsum in the upper part.

f Thin cellular quartz on beds and sandy marls.

e Thick red marls. This is the main part of the series. (Calamites.)

d Several beds of thin White and Red sandstone, alternating with the argillaceous strata.

c White sandstones, sometimes firm, but often soft, and in a peculiarly concretionary or lumpy state—no fossils.

b Sandstones and conglomerates, 200 to 400 feet. Red sandstones, often conglomeritic with quartz pebbles, and interstratified with red sandy shales—a fossil found at Broomsgrove.

a Peculiar pebbly Permian conglomerate, of limited extent, on the eastern side of the Abberley and Malvern Hills, remarkable for the abundance of trappean masses included, (whence its title of trappoid conglomerate) especially in the Abberley district. It is not specially allied to the beds above; may be thought unconformed to them; perhaps may really be a Permian rock, of the age of the magnesian and trappoid conglomerates which occur against the coal fields of Shropshire and South Staffordshire. It rises to the height of 985 feet in the Abberley Hills.—Thickness, 0 to 200 feet—no fossils, except such as occur in the pebbles.

In all other districts of England we find the Poikilitic series to consist, in the same manner, of thick red marls (*d* to *m*) above, often embodying gypsum, and thin laminated, whitish or greenish sandstones (waterstone) and white and Red sandstones, generally resting on conglomerates (*b* to *c*) below. The Keuper is not yet traced with certainty north of Warwickshire. The uppermost bed (*m*) is generally found below the lias. The peculiar conglomerate (*a*) fails in the north of England, unless it be represented by magnesian conglomerate, or Rotheliegende (Permian). The only district where details of importance are added to the section in the Vale of Severn is the salt region of Cheshire. Mr. Ormerod finds in that district the total thickness of Red sandstones and marls to be at least 1,700 feet, of which the upper group, including the salt and gypsum, takes about 700 feet; the middle group, containing laminated sandstones, called waterstone, 400 feet; and the subjacent sandstones, mostly red, and partially conglomeritic, believed to correspond with the "Bunter sandstone" of Germany, 600 feet.

Rock Salt.—Mr. Holland's paper in the *Geological Transactions*, vol. i., describes the situation and mode of deposition of the rock salt in Cheshire. Cheshire unites with the southern part of Lancashire and the northern part of Shropshire into a great plain, fifty miles long from north to south, and about twenty-five or thirty wide. It is bounded on the east and on the west, and interruptedly on the south, by carboniferous ranges of hills; and the internal area is divided by two ranges of rising ground into three minor plains, which serve to conduct the Dee, the Weaver, and the Mersey to the Irish Channel. The range of Delamere Forest on the west, and an undulated tract ranging nearly westward to Halton and Runcorn, define the drainage of the Weaver, and include the most abundant sources of salt. Scarcely any rock salt is found except in this limited

tract. On approaching the estuary of the Mersey, the ridges which bound the plain approach one another at two points, and suggest the idea of the included plain having been once a lake.

The salt which lies under this plain is found to thicken, at least partially, toward the contraction of the valley; it does not, however, lie beneath the whole surface of the low ground, nor indeed in one connected mass, but occurs in detached flattened masses of limited area. The rock salt of Northwich ranges north-east and south-west, and its breadth is about three-quarters of a mile. The upper bed is thickest on the north-west, and thins off towards the south-east.

Two beds of salt at Northwich, &c.	Three beds at Lawton.
Rock salt, 84 to 90 feet.	42 yards marl, &c.
Parting of marls, &c. } 30 feet.	4 feet salt.
	10 yards marl, &c.
	12 feet salt.
Rock salt, 96 to 117 feet, and more.	15 yards marl, &c.
	24 yards salt.

The upper bed has been worked through only at Northwich and Lawton. No marine exuviæ occur over the salt, or in any way associated with it. The purest part of the salt in the upper bed is about three or four yards above the bottom of the bed, and about four feet in thickness; the purest part of the lower bed is twenty or twenty-five yards deep in it, and five or six yards thick, below which the salt becomes earthy as above. This is the part worked. The salt is not stratified, but divided into vertical prisms of various polyhedral forms, and different magnitudes, sometimes a yard or more in diameter. The sides of these prisms consist of pure white salt. Gypsum abounds in the marls associated with the salt, the most abundant variety being the fibrous kind.

Mr. Holland supposes that what is now the salt field was once a salt water lake, separated from the sea by a natural dam; that the evaporation of the water caused the precipitation of the salt, and that it was afterwards covered with the laminated marls. To account for so much salt, he imagines that the sea might often overpass the dam.

Perhaps we may say that there was here a lake of salt water, whether left as a lagoon by the retirement of the sea, or by the elevation of the land, or formed by the influx of streams which had no outlet; that in this lake the deposit of salt went on gradually, and that at intervals violent floods filling it with muddy matter, this was precipitated with gypsum, but without salt, but that afterwards the water again subsiding, salt fell as before. If the floods came in from the sea, this might explain the correspondence in character of these gypseous marls, and those which elsewhere belong to the Keuper era.

Section at Northwich.—

No.	yds.	ft.	in.	
1	5	0	0	Calcareous marl.
2	*1	1	6	Indurated red clay.
3	2	1	0	*Indurated blue clay.
4	1	2	0	Argillaceous marl.
5	0	1	0	*Indurated blue clay.
6	*1	1	0	Red clay, with sulphate of lime irregularly intersecting it.
7	1	1	0	*Indurated blue and brown clay, with grains of sulphate of lime interspersed.
8	4	0	0	Indurated brown clay, with much sulphate of lime crystallized in irregular masses.
9	1	1	6	*Indurated blue clay laminated with sulphate of lime.
10	1	1	0	Argillaceous marl.
11	1	0	0	Indurated brown clay laminated with sulphate of lime.
12	1	0	0	*Indurated blue clay laminated with sulphate of lime.
13	*4	0	0	*Indurated red and blue clay.
14	4	0	0	Indurated brown clay, with sand and sulphate of lime irregularly interspersed through it. The fresh water (360 gallons per minute) finds its way through holes in this stratum, and has its level at 16 yards from the surface.
15	1	2	0	Argillaceous marl.
16	1	0	9	*Indurated blue clay with sand and grains of sulphate of lime.
17	5	0	0	Indurated brown clay with a little sulphate of lime.
18	0	1	6	*Indurated blue clay with grains of sulphate of lime.
19	2	1	0	Indurated brown clay with sulphate of lime.
20	25	0	0	Rock Salt.
21	10	1	6	Layers of indurated clay with veins of rock salt (occasioned by water filtering) running through them.
	76	1	9	
22	36	0	0	Rock Salt sunk into 35 or 36 yards.

Rock salt is a frequent but not an exclusive production of the red marl and Red sandstone; the mines of Wielitzka are in tertiary green sand, those in the Salzburg Alps in limestone of the oolitic period.

By far the larger proportion of ordinary springs, from whatever strata they issue, yield chloride of sodium, sometimes in very large quantity, and it is important to know that bromine and iodine, which are stated to be always existent in the actual sea water, very generally accompany the muriatic salts in common springs. This is most remarkably the case with bromine. (See *Phil. Trans.* 1830.) The rock salt of Cheshire is perhaps entirely devoid of bromine and iodine, though the brine springs of the same district are found to contain both. The reason of this may be, that the hydrobromic and hydriodic salts have not the same ratio of solubility as the chloride of sodium.

Foreign Localities.—The distribution of the Poikilitic series in foreign countries is extensive, especially in France and Germany, where, mantling round, or resting against the mountain tracts of the Vosges, Schwartzwald, Odenwald, Spessart, Thuringerwald, and

Hartz, the sandstones and marls contain a calcareous rock at present unknown in England, called the muschelkalk, which in some of its external characters, particularly its smoke-gray colour and association with marls, bears a considerable analogy to the upper layers of the magnesian limestones of England, but by the occasional abundance and general character of its organic remains, is strongly assimilated to our lias.

In several districts, especially in Wurtemburg, the sandstones and marls contain organic remains, both animal and vegetable, which are entirely distinct from those yet known to belong to the older formations, but greatly resembling those of the lias and oolites, so that the foreign localities supply us with links in the chain of geological facts which were wanting in England, and which were necessary to a true estimate of the relation of the saliferous system to earlier and later deposits.

Salt which, as above explained, occurs in England in beds only in the variegated marls, is found on one or other side of the Rhine in every bed of the system.

From these remarks it is evident that there is a great general resemblance between the characters of the saliferous formation as it exists in Germany, France, and England; but to make the differences equally apparent, it will only be necessary to fix our attention upon two districts in particular, viz., the Vosges mountains, which range to the north-east parallel to the Rhine, and the district in the north-east of Upper Germany, adjoining the Thuringerwald and the Hartz mountains.

The general succession of strata in the saliferous system round the Vosges mountains may be well seen on the road from Metz to Strasburg; and the minuter details of the beds have been ascertained by those eminent geologists, Voltz and Elie de Beaumont; to the former of whom we owe the discovery of most of the vegetable fossils of these rocks, and to the latter a valuable discussion of the relations of the formations.

Between the bottom of the oolitic system and the top of the saliferous system occurs, about Luxemburg especially, a peculiar sandstone, which has hardly been distinctly recognized in any other situation. Below this, in descending order, is the following series of strata:—

Section of the Vosges.—4. Variegated marls, Keuper of Germany, marnes irisées of France.—Red, pale blue, greenish, &c., with gypsum occasionally interstratified, especially near the top, with beds of sandstone of different kinds, containing plants of the families calamites, equisetaceæ, lycopodiaceæ, coniferæ, cycadeæ, &c., univalve and bivalve shells, remains of saurians and chelonida.

In these coloured marls, above the middle, lies a regular bed (six

to ten feet thick) of extremely compact magnesian, yellow limestone, without fossils, and under it, in several places, black schistose marls; in this part, also, gypsum is especially abundant. In several situations, thin bands of reddish limestone occur, alternating with anhydrite.

3. Muschelkalk.—Limestone, generally compact, of a light gray or smoky colour, with partings of marl, containing peculiar encrinites, with ceratites, plagiostomata, and other shells analogous to those of the oolitic system, and remains of reptiles. Near Luxemburg it is very thin, and may easily be mistaken for lias; near Saverne it is much thicker, and more characteristic. At Bourbonne les Bains it is a true magnesian limestone. As before observed, it does not exist in England.

2. Variegated red sandstone. (*Bunter sandstein* of Germany, *grès bigarré* of France.)—Extremely similar to the new Red sandstone of England. This also contains, locally, abundance of organic remains, both animal and vegetable.

1. The strata above named rest, in some places unconformably, upon a vast thickness of Red sandstone, in general much coarser, and more like a conglomerate than the variegated Red sandstone; the pebbles of quartz, which it contains in abundance, appearing to be derived from the ruins of portions of the primary rocks of the range of the Vosges. The magnificent precipices down which the road descends to Saverne, among grand old woods and torrents, are formed by this rock; and the resemblance which it bears to the old Red sandstone conglomerate of Monmouthshire, is such as to bias the English geologist strongly in favour of that approximation. In other cases, and especially in hand specimens, this rock appears to resemble the coarse Red sandstone of Dumfriesshire and of Penrith Beacon, and as these rocks certainly overlie the carboniferous series, this comparison may, perhaps, be exact. The northern part of the Vosges mountains being wholly composed of these grit rocks, and coal beds being found at many points in the same vicinity, the incumbency of the Red sandstone upon the coal is satisfactorily proved.

The lower part of this thick arenaceous group, which rests upon the coal series, is usually of a friable and fragmentary nature, containing admixtures of porphyritic masses, which strongly assimilate it to the Red sandstone conglomerate of Exeter, and the Red sandstone, expressly so called, of the north of Germany. The upper part, also, gradually becomes finer grained, and more like the ordinary variegated Red sandstone; but as in several places this latter rock rests unconformably upon the other, we are justified in adopting the opinion of Voltz and De Beaumont, that it is a portion of the Red sandstone series, almost peculiar to the Vosges mountains, and

may, therefore, be characterized as the *grès des Vosges.* The lower part of it is regarded by Murchison as "Permian."

North-East of Germany.—The north-east of Germany gives us the following section of the saliferous system :—

3. Variegated marls (*Keuper, marnes irisées*) with gypsum, and the usual characters of the strata.

2. The muschelkalk, much as it occurs about the Vosges. It admits of subdivision into two, or, perhaps, three parts, which according to Hoffman, may be distinguished by their respective types of organic remains.

1. Variegated sandstone. (*Bunter sandstein, grès bigarré.*)

Below are zechstein and *rothetodteliegende.*

The following table will show the relations of the three tracts :—

England.	France.	Germany.
Variegated marls.	Marnes irisées.	Keuper.
	Muschelkalk.	Muschelkalk.
Variegated sandstone.	Grès bigarré.	Bunter sandstein.
	Grès des Vosges.	

With respect to organic remains, it may be sufficient to remark generally that they are found locally in abundance in all the members of the saliferous series in Germany and France, while hitherto they have scarcely appeared in England.

Salt.—It appears that the greater part of the salt beds of Germany occur in the muschelkalk, between Magdeburg and Osnabruck, and in the Valley of the Neckar in Wurtemberg. At Vic, Baden, and Lons le Saulnier, salt lies in red marl, along the north side of the Tyrolean Alps, in Red sandstone (Altenau, Berchtolgaden), and it is possible that the abundant salt-works on both sides of the Carpathians in Transylvania and Moldavia may be established on this series. The salt of European Russia (Strangways, in *Geol. Trans.*) is connected with the new Red and Permian sandstone; so most probably the salt amongst the sands (said to be red) of Persia, and in India between the Indus and Chellum, but regarding the deposits in Africa, New Holland, and North America, we desire further information. The salt of Cordova, in Spain, and various points along the line of the Pyrenees, appears to lie in green sand; that of the Salzburg Alps belongs to alpine limestone of the oolitic area, while in Sicily salt is found in sulphureous tertiary marl, and at Wielitzka it lies in tertiary strata containing a few shells.

Circumstances attending the Origin of the Saliferous System.

Its Marine Origin.—From the preceding statement we may confidently decide that the whole of the strata belonging to the saliferous

system were deposited in the sea around the previously elevated lines of older rocks. The mechanical aggregates of sandstone, and clays, and marls, do not in general show us those exceedingly fine laminations and indefinitely numerous alternations of different materials which mark the coal deposits, they do not abound in such a multitude of spoils of the land, nor contain extended layers of the reliquiæ of fresh water. Had he never known of the local accumulations of fossil plants in the Keuper, and variegated sandstones of the continent of Europe, the English geologist might have consistently doubted whether inundations from the land had ever disturbed the regular operations of the sea during this period. To explain this irregularity of distribution of terrestrial plants, it may be supposed that inundations of the land happened only in particular places along the margin of that ancient sea, or it may be said that the inundations being general, the growth of plants was limited. With respect to the accumulations of the rocks themselves, equal difference of opinion may be indulged; for if the remarkable absence, from the greater part of the area of the saliferous system, of any marine exuviæ in the mechanical aggregates might favour the notion of the materials being wholly derived from the land, yet the mere fact of the extraordinary and connected extent, the remarkable *uniformity of character of these extensive deposits*, even where the more anciently elevated strata round which they were evidently formed are of entirely different nature, and their apparent *independence* of these boundaries of their surface, seem to prove either—1, that the materials were collected by the action of the sea itself; or 2, that when brought into it by other agents, they were for very long times exposed to its equalizing action.

This long action of the waves upon the particles of the siliceous and aluminous rocks and minerals which compose the mechanical aggregates and sedimentary deposits of the saliferous system, is also suggested by the amazing prevalence of the colour of peroxide of iron, which covers as a varnish so many of the particles; and it is confirmed by the discoveries of the organic remains, since these are of such a nature as to prove that during the period when peroxides were so prevalent, the last types of the living creation of the carboniferous period came to an end, and were replaced by other tribes, which likewise finished their career and yielded to the more numerous races which fill the oolitic rocks.

Salt and Gypsum.—The salt and gypsum usually associated in this remarkable system present also their difficulties. Not that it is hard to suppose the waters of the ancient sea to have been so evaporated as to permit first the crystallization of sulphate of lime, and finally of muriate of soda. But in this case we should expect to find almost uniformly over the whole area regular strata of gypsum

below, and regular layers of salt above, while, in fact, we more commonly find salt in great broad masses rather than beds below, and gypsum in scattered masses above. A general drying of the waters in which the saliferous system was deposited is plainly inconsistent with probability; and we must have recourse to local causes, something analogous perhaps to those which influenced the deposit of primary limestone. It may be conceivable that the solubility of muriate of soda in water is capable of diminution through the admixture of other substances in the liquid, or through the effects of great pressure, or of pressure and heat combined; it may be maintained that the limited deposits of salt happened in separated lagoons of the sea, exposed to local desiccation, as perhaps in Cheshire. Lyell has still a different and less probable view of the subject. All these explanations assume that the salt was produced directly by *mere* crystallization, from waters almost perfectly analogous to those of the actual seas; an assumption strongly confirmed by the recent discoveries connected with bromine and iodine.

Further researches, both chemical and geological, must determine between these and other theories, and, in particular, we must be more exactly informed of the ancient hydrography of the salt districts, which, in almost every instance, must have been very different from their present topographical features.

Organic Remains.

The Poikilitic group yields in the British Isles very few fossils. In the sandy beds to which specially the name of Keuper was given, we find a few plants, shells, and remains of fishes; and this small catalogue is augmented by the reptiles of Warwickshire and perhaps of Bristol (unless one of these localities belong to the Permian group). The sandstones of Dumfriesshire, Liverpool, &c., have yielded to Sir W. Jardine and others a large series of footprints of reptiles.* The bone beds of Aust lie at the base of the lias; but Sir P. Egerton regards the organic remains in them as really Keuperian.

PLANTS,	Dictyophyllum crassinervium,	near Liverpool.
	Echinostachys oblongus,	Bromsgrove.
	Walchia hypnoides,	Warwickshire.
	Convallarites,	Do.
MONOMYARIA,	Posidonomya minuta,	Shrewsbury Common, Salop, near Pendock.
DIMYARIA,	Pullastra arenicola,	Near Pendock.
FISHES,	Dipteronotus cyphus,†	Bromsgrove, in Bunter Sandstein.
	Hybodus Keuperi,	Pendock, Burgehill, &c.

* Ichno. Annan.

† This is a homocercal fish, and thus contrasted with the Palæozoic races, but allied to the Mesozoic forms.

The following are from the bone bed:—

Acrodus minutus.	Gyrolepis Alberti.
Ceratodus altus.	tenuistriatus.
curvus.	Hybodus læviusculus.
dædaleus.	minor.
disouris.	plicatilis.
emarginatus.	Nemacanthus filifer.
gibbus.	monilifer.
latissimus.	Saurichthys apicalis.
obtusus.	
parvus.	
planus.	

REPTILIA,	Cladyodon Lloydii,	near Warwick, near Leamington.
	Labyrinthodon Bucklandi,	Warwickshire.
	giganteus,	Guy's Cliff.
	leptognathus,	near Warwick, Cullington.
	scutulatus,	Leamington.
	ventricosus,	near Warwick.
	Rhynohosaurus articeps,	Grinsill, Warwickshire.
	Thecodontosaurus,	Rutland, Bristol.
	——— sp.	Leamington.

The following are from the bone bed:—

	Plesiosaurus costatus,	Aust.
	Hawkinsii,	Do.
	trigonus?	Do.
	Rysosteus,	Do.
ICHNITES,*	Actibatus Triassæ,	Corncockle Muir, Dumfries.
	Batrichnis Lyellii,	Green Mill, near Dumfries.
	——— Stricklandi,	Dumfries.
	Cheirotherium Hercules,	Tarporley, Cheshire.
	Kaupii,	Lymm, Cheshire.
	———	Storeton, Cheshire.
	———	Lymm.
	———	Annan.
	Chelaspodos Jardinii,	Dumfries.
	Chelichnis ambiguus,	Corncockle Muir.
	Duncani,	Do.
	gigas,	Do.
	obliguus,	Do.
	plagiostopus,	Do.
	plancus,	Do.
	Titan,	Do.
	———	Weston, near Runcorn.
	Herpetichnis Bucklandi,	Corncockle Muir.
	Sauroplesius,	Do.
	Saurichnis acutus,	Dumfries.

Beyond the British dominions, Europe yields a much larger, but still a limited series of life in the Triassic strata, none of the

* Jardine, Ichnology of Annandale.

members of the group being absolutely void of organic remains. The following lists, drawn up in 1833, will furnish a general idea of this comparatively small flora and fauna:—

Table of the Organic Remains of the Saliferous System.

The asterisk distinguishes such as are known to occur in other systems of strata.

PLANTS.

	Family and Name.	Locality in Keuper.	Locality in Muschelkalk.	Locality in Bunter Sandstone.
Cryptogamia.	Equisetum Meriani,	Neue Welt, near Basle.		
	columnare,	Wurtemberg,		Sulzbad, or Soultz.
	platyodon,	Franken, in Wurtem.		
	Calamites arenaceus,	Do.,		Wasselone, Marmoutier.
	Mougeottii,			Marmoutier.
	remotus,			Wasselone.
	Pecopteris Meriani,	Neue Welt.		
	Tæniopteris vittata,	Neue Welt, Stuttgart.		
	Anomopteris Mougeotti,			Soultz, Wasselone.
	Neuropteris Voltzii,			Soultz.
	elegans,			Do.
	Gaillardoti,		Luneville.	
	Sphænopteris myriophyllum,			Do.
	palmetta,			Do.
	Filicites Stuttgartensis,	Stuttgart.		
	lanceolata,	Do.		
	scolopendrioides,			Do.
Cycadeæ.	Pterophyllum longifolium,	Neue Welt.		
	Meriani,	Do.		
	Jægeri,	Franken, Stuttgart.		
	enerve,	Neue Welt.		
	Mantellia cylindrica,		Do.	
Various Families.	Convallarites erecta,			Do.
	nutans,			Do.
	Palæoxyris regularis,			Do.
	Echinostachys oblongus,			Do.
	Æthophyllum stipulare,			Do.
	Marantoidea arenacea,	Stuttgart.		
	Voltzia brevifolia,			Do.
	elegans,			Do.
	rigida,			Do.
	acutifolia,			Do.
	pterophylla,			Do.

The names in this list are taken from M. Brongniart, who supposes the flora of the variegated sandstone system to be of a peculiar type. It is certainly very analogous to that of the succeeding or oolitic epoch, by its pterophylla and equiseta, but the genus Voltzia is perhaps peculiar to it.

POLYPARIA.

The absence of polyparia from the muschelkalk is one of the characters by which it approximates to the lias.

RADIARIA.

Name.	Locality in Keuper.	Locality in Muschelkalk.
Ophiura prisca, Mün.,	Vosges Mountains,	Baireuth.
loricata, G.,	Schwenningen.	
Asterias obtusa, G.,		Marbach.
Encrinus moniliformis, Mil.,		General in this rock.
Pentacrinus dubius, Gold.,		? Rudersdorf.

ANNULOSA.

Name.	Locality in Muschelkalk.
Serpula valvata, G.,	Baireuth.
colubrina	?

By its radiaria, amongst which no echinus is mentioned, the muschelkalk resembles the lias.

CONCHIFERA.

	Family and Name.	Locality in Keuper.	Locality in Muschelkalk.	Locality in Bunter Sandstone.
Plagimyona.	Cardium pectinatum, v. Alberti,	Wurtemberg,	Wurtemberg.	
	striatum, Schl.,		Do., Gottingen.	
	Trigonia vulgaris, Schl.,	Ludwigsburg,	Weimar, Gottingen, Wurtemberg, Baireuth,	Domptail, Soultz.
	curvirostris, Schl.,	Do., Schwenningen,	Wurtemberg.	
	sulcata, G.,	Villingen.		
	pes anseris, Schl.,		Gottingen, Morsbach, Luneville.	
	cardissoïdes, G.,		Wurtemberg.	
	lævigata, G.,		Marbach.	
	Goldfussii, v. Alberti,		Do.	
	Mya musculoïdes, Schl.,	Sultz on the Neckar,	Weimar, Wurtemberg, Upper Silesia, Poland,	Sulzbad.
	elongata, Schl.,	Do.,	Wurtemberg, near Waldshut, Upper Silesia, Poland,	Sulzbad.
	ventricosa, Schl.,		Wurtem., Luneville.	
	mactroides, Schl.,		Marbach, Upper Silesia, Poland.	
	rugosa, v. Alberti,		Rottweil.	
	Modiola minuta, G.,	Rottweil.		
	Mytilus vetustus, G., eduliformis, Schl.,		Gottingen, Wurtemberg, Luneville, Baireuth,	Domptail, Sulzbad.
	Venericardia Goldfussi v. Alberti,	Rottweil.		
	Saxicava Blainvillii, Hæn,	?		
	Venus nuda, G.,		Marbach.	
	Mactra ? trigona, G.,		Do.	
	Arca inæquivalvis, G.,		Freudenstadt.	
	Cucullæa minuta, G.,		Villingen.	

	Family and Name.	Locality in Keuper.	Locality in Muschelkalk.	Locality in Poikilitic Sandstone.
Mesomyona.	Plagiostoma lineatum, Schl.,	Wurtemberg,	Morsbach, Michelstadt, Gottingen, Wurtemberg, Baireuth, Weimar.	
	striatum, Schl.,		Very common.	
	rigidum, Schl.,		Jena.	
	lævigatum, Schl.,		Morsbach.	
	punctatum, Schl.,		Gottingen, Gotha, Weimar, Baireuth, Toulon.	
	Avicula socialis, Schl.,	Sulz on the Neckar,	Very generally distributed,	Sulzbad, Domptail.
	subcostata, G.,	Do.,	Wurtemb., Baireuth.	
	lineata, G.,	Do.		
	crispata, G.,		Friedrickshall.	
	Bronnii, v. Alberti,		Villingen.	
	costata,			Sulzbad.
	Posidonia Keuperiana, Voltz,	Swabia, Hall.		
	minuta, v. Alberti,	Rottweil.		
	Ostrea placunoides, Mun.,		Baireuth.	
	subanomia, M.,		Do.	
	reniformis, M.,		Do.	
	difformis, Schl.,		Wurtemberg.	
	multicostata, M.,		Wurzburg.	
	complicata, G.,		Baireuth, Villingen.	
	decemcostata, M.,		Baireuth.	
	spondyloides, Schl.,		Very general.	
	comta, G.,		Rottweil.	
	pleuronectites, Schl.,		Bourbonne les Bains, Luneville.	
	Gryphæa ? prisca, G.,		Villingen.	
	Pecten reticulatus, Schl.,		Gottingen, Gotha.	
	Alberti, G.,		Villin., Rudersdorf.	
	lævigatus, G.,		Wurtemberg, Baireuth, Gotha.	
	discites, Schl.,		Wurtemberg, Pohlen, &c.	
	Perna vetusta, G.,	Durrheim.		
Brachiopoda.	Lingula tenuissima, Bronn,	Rottweil,	Rottweil.	
	Terebratula communis, Bosc., vulg. et subrot. Schl.		Gottingen, Wurtemberg, Luneville, Bourbonne les Bains, Toulon.	
	perovalis, Schl.,		Jena.	
	sufflata, Schl.,		Do.	
	orbiculata, Schl.,		Near Jena.	
	Spirifer, Sow, semicircularis, G.,		Villingen.	

GASTEROPODA.

	Family and Name.	Locality in Keuper.	Locality in Muschelkalk.	Locality in Poikilitic Sandstone.
Holostomata.	Calyptræa discoides, Schl.,		Villengen.	
	Capulus, or Pileopsis mitratus, G.,		Do.	
	Dentalium torquatum, Schl.		Gottingen.	
	læve, Schl.,		Do., Alpirsbach, Baireuth.	
	Trochus albertinus, G.,		Rottweil.	
	Turbo? dubius, Mun.,		Seewangen, Riedern, near Waldshut.	
	? giganteus, Schl.,		Seewangen.	
	Turritella obsoleta, Schl.,		Weimar, Gottingen.	
	deperdita, G.,		Weimar.	
	detrita, G.,		Culmbach.	
	scalata, Schl.,		Wurtemberg, Rudersdorf.	
	? terebralis, Schl.,		Weimar,	Domptail, Sulzbad.
	Schoteri,			Sulzbad.
Solenostomata.	Buccinum turbilinum,	Sulz on the Neckar,	Wurtemberg, Seewangen, Rudersdorf.	
	gregarium, Schl.,		Rudersdorf.	
	antiquum, G.,			Sulzbad.

CEPHALOPODA.

Name.	Locality in Muschelkalk.
Nautilus bidorsatus, Schl.,	Weimar, Rudersdorf, Gottingen, Wurtemberg, Luneville.
nodosus, Mun.,	Franken.
Ammonites, nodosus, Schl.,	Weimar, Gottingen, Wurtemberg, Lorraine, Toulon, Tarnowitz.
bipartitus, Gaill.,	Luneville.
semipartitus, Schl.,	Luneville.
Rhyncholites Gaillardoti d'Orb.,	Jena, Gottingen, Wurtemberg, Luneville, Rehainvillers.
hirundo, Fauv.,	Wurtemberg, Luneville.

These cephalopoda are characteristic of the muschelkalk. The ammonites belong to a section of that numerous genus, distinguished by peculiar sutures, and called Ceratites. See Von Buch's Essay on the subject of the sutures of ammonites.—(*Ann. des Sci. Nat.*)

CRUSTACEA.

Name.	Locality in Muschelkalk.
Palinurus Suerii, Desm.,	Villingen, near Saarbruck.

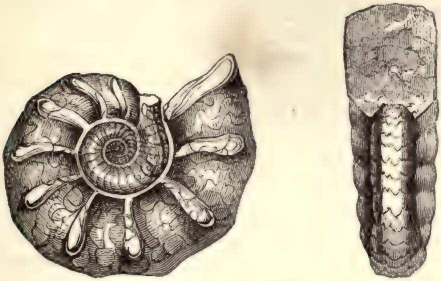
VERTEBRATA.

Name.	Locality in Keuper.	Locality in Muschelkalk.
Fishes,	Seidmannsdorf, Neuses, Seidingstadt, near Coburg,	Baireuth.
Teeth of Sharks, &c.,	Wurtemberg,	Wurtemberg, Rudersdorf.
Phytosaurus cylindricon, Jæg.,	Boll.	
cubicodon, Jæg.,	Do.	
Mastodonsaurus Jægeri, Holl.,	Gaildorf.	
Ichthyosaurus Lunevillensis,	Wurtemberg,	Luneville, Wurtemberg.
Plesiosaurus,	Durrheim,	Wurtemberg, Baireuth, Rudersdorf.

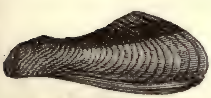
Crocodilus, ...	Rudersdorf.
Large saurian, ...	Luneville.
Chelonia, ...	Do., Bindlocher, and Leineckerburg.

It is unnecessary to point out the obvious and almost universal difference between this last and any of those which represent the earlier Palæozoic life. Like the oldest of those rocks, so this the first of the Mesozoic groups is poor in all the forms of life. Those which do appear are generally analogous to, and often congeneric with, the more numerous groups of middle Mesozoic plants and animals.

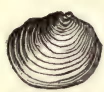
SALIFEROUS FOSSILS.



186

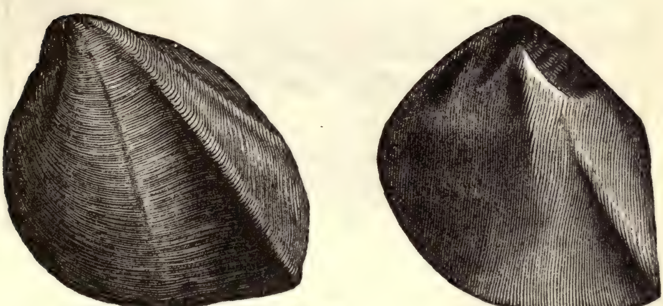


187



188

189



190

186 Ammonites (Ceratites) nodosus. 187 Avicula socialis. 188 Posidonia minuta. 189 Encrinites moniliformis. 190 Trigonia vulgaris.

191

192

191 Pterophyllum Pleiningerii. 192 Voltzia heterophylla.

CHAPTER X.

MIDDLE MESOZOIC STRATA.

Disturbances of the New Red Series.

In England dislocations on a very extensive scale are but rarely exemplified in strata more recent than the coal measures. Several upward and downward movements of the land, and consequent great changes of level, certainly occurred. One long axis of movement is traceable in the Wealds of Sussex, another in the Isles of Wight and Purbeck; but it appears that this part of the surface of the globe enjoyed a long and rarely interrupted immunity from those violent agencies which had previously shaken its strata into such disturbed positions. A few faults in the magnesian limestone range of Durham and Yorkshire, as along the line of the great whin dike through those counties, in the country between Doncaster and Ferrybridge, and south of Doncaster, may be mentioned rather as exceptions to the general rule, effected in some indefinite portion of the long period succeeding the deposit of coal; and the curious parallel faults of Aust cliff on the Severn, which affect both the lias and red marl, deserve attention, in connection with the law formerly laid down of faults underlying depressed portions of strata.

Neither on the continent of Europe are the dislocations of the saliferous system so remarkable as those of the older strata. In the Vosges mountains we have, however, a splendid example of a dislocation on a great scale, by which, in a direction north-east and south-west, the lower strata of this system (*grès des* Vosges) are thrown up into bold mountains, while the upper beds of the same system (muschelkalk and keuper) are left several hundred feet below the magnificent escarpment. In fact, it appears that this eruption happened after the date of the grès des Vosges, and before the muschelkalk and keuper were deposited.

Unconformity and interruption of continuity between the variegated marls and the oolitic formation above are but local effects; parallelism of strata generally prevails between these contiguous systems, indicating freedom from general disturbance, and in some instances, especially in Somersetshire, the frequent changes of colour in the upper red marls, and finally the interposition of a purple or black marl, which is not more related to the lias than to the subjacent system, appear to show that even in the nature of the deposits there is no more decided difference between them than between any other successions of strata.

Oolitic System.

The oolitic system of strata has for the most part its ranges parallel, and its declinations accordant to the saliferous rocks, and was deposited in the same marine basins. The general character of the rocks, and the nature of the organic remains are, however, extremely different, but the change from the one system to the other, though seldom to be called gradual, is accomplished by remarkable repetitions. In particular, the muschelkalk of Germany and France represents or anticipates, even in mineralogical characters, but more decidedly in its suite of organic exuviæ, the lias, which is at the base of the oolitic system. Through all the mass of the oolitic system, consisting of various limestones, clays, and sands, the most remarkable repetitions occur. The mass of lias contains beds very nearly approaching to the ferruginous inferior oolite; three or four separate beds of very similar oolite, several beds of sand and sandstone also remarkably analogous, and many thick strata of clay hardly distinguishable except by their organic reliquiæ, make up this vast argillo-arenaceo-calcareous mass, of which the top changes, by repeated introductions of green sand layers, to the real cretaceous system, as the bottom has been before shown to be partially connected with the saliferous group.

The composition of this system varies much in different countries of Europe, according, probably, to the differences of depth of the original waters, proximity to land, to mouths of ancient rivers, &c. In consequence, while on the border of Switzerland it is almost wholly calcareous, in Westphalia and in England its limestones are much intercalated with clay, and occasionally with carboniferous sandstones and shales, hardly to be distinguished from those of the older coal strata. A remarkable absence of metallic substances is a character of the calcareous portions of this system (excepting the lias) in all its extent.

The most distinct classification of the oolitic system will be obtained from the combined section of the English series; for though the total thickness of the deposit is perhaps greater in the south-east of France and in Switzerland, the number of divisions is there less, the mass more uniformly calcareous, and the parts less characteristic.

The oolitic system of England everywhere admits of the following mode of subdivision, though in some tracts particular groups are concealed by unconformity or entirely wanting. The groups are placed as they occur in nature, or the series is descending; the numbers indicate the order of time:—

5. Wealden formation.	A series of clays, sandstones, and limestones, mostly of fluviatile origin, and containing remains of land and fresh water animals and plants, deposited in estuaries or other local hollows of the really marine portion of the oolitic system.
4. Upper or Portland oolite formation.	Calcareous, sometimes oolitic rocks, associated with green and irony sands, resting on blue clay, altogether marine deposits. When the Wealden formation is absent (as happens in the greater number of instances) this terminates the whole system, and graduates into the cretaceous rocks above.
3. Middle oolite or coralline formation.	Consisting of oolite and other limestone strata, included in calcareous gritstones, and resting on blue clay and calcareous gritstone: altogether marine deposits.
2. Lower or Bath oolite formation.	Consisting of two or more strata of oolite, with other calcareous beds, and alternations of sands and clays, which in particular districts enlarge themselves into real coal tracts. Altogether marine and littoral deposits.
1. Lias formation.	Consisting principally of argillaceous clays, more or less laminated, and including, especially in the lower part, layers and nodules of generally argillaceous limestone, and in the upper part bands and strata ferruginous, calcareous, and arenaceous, which strongly resemble the bottom of the lower oolite formation.

A further analysis of these formations presents us with the following details:—

5. Wealden formation of Kent, Sussex, and Hampshire.		*Weald clay.*—Thick blue clays, generally destitute of organic remains, except in certain calcareous beds, which contain fresh water shells. *Hastings' sands.*—Thick series of sandstones, with partings of clay, and subordinate beds of limestone, with bones of saurians, fluviatile shells, and land plants. *Purbeck beds.*—Blue clays and laminated limestones with fresh water and estuary shells.
4. Upper oolite formation of Portland, Wilts, Bucks, Berks, &c.		*Portland oolite.*—Oolite and earthy and compact limestones with marine shells, and layers of nodular chert. *Shotover sand.*—Calcareous sand and concretions. *Kimmeridge clay.*—Thick blue clay, bituminous, with septaria and marine remains, and especially in the lower part, bands of sandy concretions, thus establishing a gradation to the next system.
3. Middle oolite formation of Oxford, Berkshire, Yorkshire, &c.	Coralline oolite group.	Upper calcareous grit, with marine fossils. Coralline oolite, so named from two or three separate beds of irregular occurrence, rich in zoophytic exuviæ. In the lower part the beds alternate with those of the next rock; all of them contain marine remains. Lower calcareous grit, with marine shells, graduating below into the Oxford clay.
	Oxford clay group.	Oxford clay, with septaria, fossils, &c.; the lower part a subordinate bed, called Kelloway rock, which is a calcareous grit, (rarely oolitic,) very rich in fossils. Blue clay dividing Kelloway rock from the cornbrash.

Formation	Group	Beds
2. Lower oolite formation in Gloucestershire, Oxfordshire, & Northamptonshire. *N.B.*—All this part of the series is differently composed in Yorkshire and North of Scotland.		Cornbrash limestone, a coarse, shelly rock of variable and small thickness, but remarkable continuity.
	Forest marble group.	Sand with concretions of sandstone and nodules of fissile arenaceous limestone.
		Coarse shelly oolite, in some places slaty.
		Sandy clay or grit.
		Blue clay of Bradford.
	Great oolite.	A calcareous and mostly oolitic rock, of variable thickness and changeable nature, the upper beds shelly, the lower sometimes laminated.
	Fuller's earth group.	A series of marls and clays with included beds of soft marly or sandy limestones and shells.
	Inferior oolite.	A coarse, often very shelly rock of limestone, irregularly oolitic, occasionally interlaminated with sand, especially in the lower part.
		Ferruginous sand with concretionary masses of sandy limestone and shells.
1. Lias formation in Yorkshire, Northamptonshire, and Somersetshire.		Upper lias clay or shale, full of belemnites and other fossils, intercalated with or graduating to the sand above, and in some cases containing nodules and bands of limestone.
		Marlstone. A suite of calcareous, sandy, and irony beds, very rich in fossils, and much analogous to the lowest beds of the lower oolite formation.
		Lower lias clay or shale, full of fossil remains, interlaminated with bands and nodules of limestone, especially in the lower part, where a collection of these layers constitutes the lias rock.
		Lias rock. A suite of laminated limestones, with partings of clay, blue, gray, and white, the former in particular containing gryphites and other shells; the latter usually devoid of organic remains. This rock is sometimes consolidated into a united mass, and sometimes divided into separate portions.
		Bone bed, and blue, black, or purple marls, which cover the new red formation in the south of England.

Range of Lias.—The lias formation is observed on the southern coast of England, at Lyme Regis, from whence, passing under the unconformable green sand of Blackdown, and surrounding the irregular elevations of carboniferous limestone in Somersetshire, it ranges uninterruptedly by Bath, Gloucester, Leicester, Newark, and Gainsborough, to the Humber. At this point the course of the oolitic system is very much narrowed by the over-extension of the chalk; and at Bishop Wilton the chalk rests on the lowest part of the lias formation, which has a superficial breadth of only a few yards. It, however, expands again towards the north, and shows itself very completely developed on the coast of Yorkshire. Detached portions of this formation accompany the new red and Permian systems in Glamorganshire, and lie unconformably in the hollows amongst elevated ridges of carboniferous limestone.

Through the whole of this range some general physical features,

almost constant mineralogical qualities, and prevalent species of organic reliquiæ, fix such a decided character upon the lias formation as to establish a good geological horizon for the guidance of the English observer.

The country which it occupies is in general a broad vale at the foot of the escarpments of oolite, and terminating towards the red marl by a very connected range of uniform low hills. A considerable portion of the steep slope of the oolite escarpments is occupied by the lias; and in the Midland Counties, particularly, owing to the action of currents of water, detached portions of oolite crown the summits of many insulated masses of the upper lias shales.

From the coldness and stiffness of the soil, much of the surface of the lias clays remains in pasture, for which it is well adapted; and where the plough has in former times been employed, the land is thrown up into very high ridges for the sake of surface drainage. Water is scarce in this tract, and, because of the abundance of pyrites, often sulphureous or ferruginous, or impregnated with purgative muriates and sulphates.

A general tendency to an argillaceous type belongs even to the limestones of the lias formation, and its clays more frequently exhibit a schistose structure than the other clays of the oolitic system. Layers and masses of jet are frequent in it, especially in the northern part of its course; pyrites is one of its most abundant productions, especially in connection with ammonites and other shells, and sulphur in some parts is so prevalent as to furnish a valuable manufacture of alum. Many fruitless trials for coal along the line of the lias clays are upon record, to serve as a warning to those unacquainted with geology.

Very remarkable organic exuviæ belong almost equally to every part of the English lias. Skeletons of saurian and chelonian reptiles, several species of scaly fishes, abundance of ammonites and belemnites, plagiostomata, gryphææ, &c., and considerable quantities of the wood of coniferous trees, enable the naturalist to form very reasonable views of the state of the ancient land and sea when this formation was in progress, and serve not only to identify it in all parts of England, but even over a large part of its extent in France and Germany.

Nevertheless, there are important geographical peculiarities connected with the lias of England, which deserve a short analysis, the better to enable us to perceive the circumstances under which the ancient sedimentary deposits of the sea took place.

Lias in Yorkshire and Lincolnshire.—The section of the lias, as it exists in Yorkshire and Lincolnshire, is peculiarly instructive and complete, and forms an excellent type with which to compare the detached portions of the formation in north Britain and the south of England. We shall take the groups in the ascending order of their antiquity.

Lias limestone. The calcareous beds included in this division are in the north of England very distinctly divided into two or more portions separated by a considerable thickness of clay.

1. The lower limestone, 10 to 20 feet thick, is not traced farther north than the Humber. It consists of compact blue or gray limestone, generally laminated and shelly, with partings of whitish clay or marl. It rests immediately upon the red marl and gypsum.

2. Clay, 50 to 100 feet, with layers of nodules, often septariate, full of pentacrinites, ammonites, plagiostomata, &c.

3. Upper lias or gryphite limestone, 12 to 20 feet, in rough, shelly, coarsely laminated beds, separated by partings of clay. The colour usually brown, but in wet pits and before exposure to the air internally blue. But the most remarkable character of these beds is the astonishing abundance of gryphæa incurva which they contain, or rather of which they almost wholly consist. In several parts of Lincolnshire the roads are mended with the most beautiful specimens of this fossil, and for miles together hardly any other shells can be collected from this part of the lias.

Lower lias clay or shale, 300 to 500 feet thick, a dark homogeneous clay or shale, with many layers of argillo-calcareous nodules, seldom containing shells, and in the lower part rough sandy beds. Coniferous wood, pentacrinites, plicatulæ, gryphæa MacCullochii, pinna folium, and several ammonites, &c., occur in this stratum, but in it organic remains are not particularly abundant, and neither belemnites, terebratulæ, nor saurians are so plentiful as in the beds above. No alum is made from this part of the lias shale.

Marlstone series, 100 to 150 feet, consisting of highly arenaceous shales, and laminated sandy limestones of brown, greenish, or gray colour, succeeded above by several bands of nodular and stratified ironstone, of immense commercial value, the whole series particularly abundant in shells, besides producing beautiful asteroidea, annulosa, and fishes. Several species of terebratulæ, cardium truncatum, dentalium giganteum, &c., appear almost confined to these strata, which likewise contain gryphææ, pectines, plagiostomata, terebratulæ, and modiolæ, not distinguishable from the ordinary fossils of the oolite. The marlstone beds are in fact the first term of the oolitic deposits, interpolated among the last terms of the lias, and, according as the clay above them is attenuated or developed, they may be ranked with the oolitic, or the lias formation. In the north of England, the former mode of arrangement *must* be adopted, but in the south, the latter has been often followed.

The upper lias clay or shale, 50 to 200 feet in thickness, is the aluminous rock of Yorkshire, and passes by intermixture into the ironstone and marlstone series below, and by a gradual change into the analogous sandy beds of the oolites above.

It contains a multitude of layers of argillo-calcareous nodules, mostly aggregated round ammonites and other organic bodies, and these are particularly remarkable and of larger size in the lower part of the shale, which also is much harder than the rest. A profusion of ammonites, belemnites, and nautili, accompanied by aviculæ, inocerami, amphidesmata, &c., besides abundance of ichthyosauri, and plesiosauri, jet, and coniferous wood, enrich this interesting rock. Its thickness is variable, amounting to 200 feet on the coast, but diminished to 50 feet, or even less, in some of the southern Cleveland hills, where also the usual smooth homogeneous texture of aluminous shale is changed to a decidedly sandy composition.

Lias in the Midland Counties.—Proceeding to the south, we find the characters of the lias formation of Yorkshire maintained with considerable exactness through the counties of Nottingham, Lincoln, Leicester, and Rutland, into Oxfordshire. The section from Lincoln to Gainsborough shows clearly the upper lias clay, marlstone group, lower lias clay, gryphite limestone, and laminated limestone, all superimposed on gypseous red marl. In the vale of Belvoir, likewise, through Rutland, and as far as the centre of Oxfordshire, we have the lower laminated limestone (1) surmounted by a thick clay, (2) in which lie gryphitic beds peculiarly shelly, which Mr. Conybeare calls *upper lias* beds, and which correspond to the gryphitic beds of Lincolnshire. Still higher, are beds of green or brown marly sandstone, with terebratulæ, pectines, belemnites, and other shells, which are always ferruginous, and, in Rutland particularly, laminated and entirely similar to some of the marlstone beds of Yorkshire. Above these, in the same tracts, lie 100 or even more feet of clay, often forming insular hills between valleys of marlstone, and upon the whole the ferruginous sand of the inferior oolite.

If any doubt has at any time been raised as to the real distinction in this country of upper lias clay, marlstone, lower lias clay, and double course of lias limestone, it has probably arisen from the extreme resemblance of the ferruginous marlstone of the Vale of Belvoir, which divides the upper from the lower lias clay to the ferruginous sandstone, which is the general floor of the oolitic rocks. In Rutland, however, the distinction is perfectly evident.

Lias of the Cottswold.—Through Oxfordshire and Gloucestershire the upper lias clay continually becomes thinner, and the marlstone beds in consequence approach nearer to the sand of the inferior oolite. It is no wonder, therefore, that they should be in these countries sometimes confounded. But the section of Painswick Hill, near Stroud, adduced by Conybeare,* sufficiently proves that the same principle of classification applies to the lias below the Cottswolds, as well as to the north-east moorlands of Yorkshire. In fact, by

* Geology of England and Wales, p. 252.

merely taking the argillaceous beds which in this section separate the sands of the oolite from those of the marlstone, and calling them upper lias clay, the accordance with the Yorkshire section is perfectly evident. This question was, indeed, effectually settled by Lonsdale's valuable investigation of the Cottswolds. That excellent observer clearly established the identity of the lias system of Gloucestershire with that of Yorkshire, in general terms; at the same time defining the amount of topographical difference which principally affects the upper lias shale.

In the southern parts of Gloucestershire, and in the vicinity of Bath, the upper lias clay becomes still more attenuated, and the marlstone beds more divided and mixed with the clay. Smith gave the name of marlstone to the laminated stony beds full of pectines and other shells which are found in the Somerset canal and other places, twenty feet or less below the sand of the inferior oolite, as may be noticed in his sections. In several places, these beds, from the deficiency of the clay above, are brought nearly into close contact with the sand of the inferior oolite.

This distinction of marlstone beds can be carried farther south, to and beyond Ilminster.

From Lonsdale's Essay in the *Geological Transactions*, we find the lias limestones to be thus arranged in the descending order:—

	Feet.
Blue lias. Consisting of beds of grayish argillaceous limestone, varying in thickness from 2 to 18 inches, and separated by others of blue marl, which are generally less than 6 inches thick, but sometimes more than 2 feet	50 to 60
White lias. Thin strata of yellowish white argillaceous limestone, with partings of pale brownish clay	10
Lower lias marl. Dark marl with calcareous concretions	20

Organic remains of ammonites, belemnites, pectens, oysters, &c., though most abundant in the blue lias, are more or less diffused through all the beds.

Combining the section of the north of England with Lonsdale's and De la Beche's sections of the lias in the vicinity of Bath and Lyme, we shall have the following general table of the complete type of the English lias:—

1. Upper lias clay, marl, or shale.	"Upper lias shale." (Phillips.)
2. Marlstone beds.	
3 Middle lias clay	Upper lias marl. (Lonsdale.) Lower lias shale. (Phillips,)
4. Lias limestones and marls	Gryphitic and laminated lias of north of England. Blue and white lias of Bath.
5. Lower lias marls and bone bed of Lyme Regis and Bath.	

These lower marls are thus described by De la Beche, at Culverhole near Lyme, (section descending):—

	Ft.	In.
Dark marl	3	0
Earthy dark gray limestone	0	10
Dark gray slaty marl	5	0
Irregular light gray limestone	0	10
Dark slaty marl	1	4
Compact gray limestone	0	10
Dark slaty marl, which rests on the light bluish-green beds belonging to the upper part of the new red sandstone system	7	0
Total	18	10

More detailed sections of the bone beds at Aust Passage and Wainlode, and Westbury Cliff, have the further advantage of disclosing the "bone bed" full of reptilian and ichthyan remains, and the limestone richly charged with insects. The interest of these situations is augmented by marks of wave action on some of the beds.* The following is the section at Wainlode, as given by Brodie:—

	Ft.	In.
Bluish clay	3	0
Hard blue limestone, ("bottom bed") with ostrea, modiola minima, and other shells	0	4
Yellow shale, with traces of fucoids	0	10
Gray and blue limestone—"*insect limestone*"	0	5
Marly clay	5	3
Hard yellow nodular limestone, "*cypris limestone*," with small shells, like *cyclas*, a species of unio, plants. (Naiadaceæ?) *Cypris*, and very rarely scales of fish (analogue of the Cotham or landscape lias of Somersetshire)	0	8
Yellow clay	9	0
Black shale	3	0
Hard gray (sandy) stone with impressions of fucoids on the upper surface, with scales and teeth of fish, viz., gyrolepis, hybodus, acrodus, and saurichthys, which also occurs in the true "bone bed"	0	1
Black slaty clay	1	6
"Pecten" bed—hard pyritous sandy stone	0	4
Black shale	8	0
"Bone bed," here hard and pyritous, composed of bones, scales, and teeth of fishes; connected with this is a white and yellow sandstone, full of casts of pullastra arenicola	0	3
Black shale	2	0
	34	8

The shore of the sea, and the vicinity of land, are clearly indicated by these deposits, which apparently change their characters or vanish in the north of England. Insects have been found by the same observer in other and higher parts of the section of the lias; as at Dumbleton, in the "fish beds" of upper lias, above the marl-

* Strickland, Geol. Proceedings. Brodie, Mem. on Fossil Insects. De la Beche, Memoirs of Geol. Survey, vol. i.

stone. Fruits have been found in the upper lias of Lincolnshire. (Morris.)

Lias in North Britain.—Murchison's *Memoirs on the Oolitic Deposits of North Britain* most clearly prove the existence of well-characterized lias shales, much like those of the Yorkshire coast, in Pabba, Skye, and other of the Western Isles, and the organic remains which he collected there are of the usual English types. Lias occurs also on the north-east coast of Ireland, as at the Giant's Causeway, with ammonites and belemnites.

The lias in South Wales is a singular extension of the formation among the dislocations of the older carboniferous system, nearly analogous to its appearance among the sandstones and slates of Scotland. The valley of the Ely, in South Glamorganshire, exhibits several upfillings of lias, commencing about five miles west of Llandaff, whence, with some interruptions, they accompany the Ely to its junction with the Channel near Penarth Point. It again appears in Barry Island, and continues to skirt the coast in a westerly direction nearly to the mouth of the Ogmore river, forming a range of bold cliffs, among which is the little harbour of Aberthaw, celebrated for the lime which it exports. (Conybeare, *Geology of England.*)

Lias in France and Germany.—We may now turn our attention to the general types of lias presented in the north and south-east of France, and in various parts of Germany.

As in England, so generally in these countries, the lias is deposited conformably to the saliferous system, but in Brittany and around the plateau of primary rocks in central France, especially about Autun, the oolitic system often touches the granitic series without any interposition of red sandstones. In the district which borders that plateau on the east, between Chalons and Autun, the oolitic rocks are considerably developed with lias at the bottom, and all based upon gypseous red marl; but the lias clays are here almost wholly deficient, and the formation consists only of the gryphitic limestone, with its partings of clay. The abundance of gryphæa incurva, and other characters of the stone, strongly remind the traveller of the analogous beds in Lincolnshire. The lias and oolites are so closely allied that Desnoyers, in his description of this tract, hesitates even to distinguish the former as a fourth stage of the calcareous or oolitic system.

South of the Ardennes mountains by Luxemburg, Metz, and Nancy, the lias exhibits more developed characters. Immediately upon the Keuper marls rests a considerable bed of sandstone, white, yellow, or rarely brown, sometimes solid, and sometimes friable; gradually passing into the lias beds above. From its abundance under and around the fortress of Luxemburg, it receives in that country the name of *grès de Luxemburg*.

The proper gryphitic lias limestones succeed and cap most of the plateaux of grit. The beds are bluish and compact, and alternate with gray friable marls.

Above are gray marls and marly grits, which correspond to the lias clays and marlstone of England; and these are followed by the ferruginous sandstones which form the general floor of the oolitic system.

In Wurtemberg, and, perhaps, generally on the German side of the Rhine, the lias has more of the character of the English series both as to mineralogical composition and organic remains. In particular, the saurian reliquiæ, so abundant in the lias clays of England, are all found in those of Boll and other parts of Wurtemberg, and with some additional species have been described by M. Jager of Stuttgart. Fine specimens of saurian animals occur in many of the museums along the Rhine. But perhaps the most remarkable accordance between the series of Germany and that of England is observed at Banz, near Coburg, where the Maine crosses the northern extremity of the Franconian range of oolites. Here Murchison has observed the following section:—

Sandstone cap of the lias..	300 feet thick.
Upper lias shale of Yorkshire..	40
Marls and marlstones..	150
Lower lias shale, with compact lias and ammonites Hawskerensis, near the top..	300
Gryphite limestone..	
Gritstone..	
Keuper formation..	

At this place the most astonishing profusion of saurians, fishes, crustacea, ammonites, nautili, and belemnites, as well as pentacrini, gryphites, and other fossils, occur; and many of them remarkably agree as to their place in the strata with the arrangement of the same species in the beds of the coast of Yorkshire.

Switzerland.—Lias shales occur below the Alpine or Jura limestone of Switzerland and Savoy, and occasionally, as at Meyringen, Bex, the Mont Joux, produce some of the characteristic ammonites and belemnites of the English lias. In the Valley of the Arve, in particular, the argillaceous beds of lias are immensely thick, and, owing to the igneous agency, once so powerfully excited beneath the Alps, have a schistose character strongly assimilating them to the primary slates. If the slates of the Valorsine belong to the same era, as their belemnitic reliquiæ indicate, the vegetable remains which they contain, being identical with those of the carboniferous epoch, would indicate that these regions enjoyed a particular immunity from the causes which, in all other instances yet examined, had wholly destroyed the plants which grew in the carboniferous epoch, and covered the earth

with cycadeæ and other entirely new types of vegetable life. The beds yielding belemnites and those containing plants *seem* to be in alternation. The whole series *seems*, at least in some localities, to dip under (or rather *toward*, for actual contact is rarely reported) the gneissic ridges of Mont Blanc, which also seem to dip under their sovereign, so as to make the whole structure "fan-shaped." This subject has provoked very many examinations and discussions. Sharpe, the latest observer, has detected the existence of several anticlinal and synclinal axes, both of "foliation" and stratification. The former structure (analogous to or identical with cleavage), being generally the most apparent, has, perhaps, most frequently caught the attention of travellers, and raised that impression, so general among the Alpine geologists, of the peculiar "fan-shaped" structure which has been found so embarrassing.*

Lower Oolite Formation.

The uninterrupted range of this formation through Dorset, Somerset, Gloucestershire, Oxon, Northamptonshire, Rutland, and Lincoln, to the banks of the Humber, may be seen on the maps of Smith or Greenough. Beyond the Humber it is concealed for a short distance beneath the overlying chalk, but emerges again, and occupies a vast breadth in the eastern part of Yorkshire. In Sutherland, and in some of the Hebrides, and particularly in Skye, it has been traced by Murchison.

It occupies, through all its course in England, an elevated range of hills with bold escarpments to the west or north-west, a gentle slope to the east or south-east, and deep valleys of denudation which often, by descending to the lias clays, furnish most complete information as to the relations of the two formations. The surface of the calcareous portions is dry and bare of trees, and wells sunk therein often reach a very considerable depth, while upon the alternating clays the soil is cold or wet, and, in general, much covered by woods. The fertility of the district is below the average of the secondary strata. The highest point of the range in the south of England is Cleeve Pipard Hill, near Cheltenham, 1,134 feet above the sea; and in the north of England, Burton Head, near Ingleby in Yorkshire, 1,485 feet; but in these cases about two-thirds of the height consists of the lias clays.

The more ordinary altitudes of the oolitic range in England are 700, 800, and 900 feet, varying according to the westward extension of the hill, the thickness of the base of lias, and the pile of incumbent strata.

* Geol. Proceedings, 1855.

Escarpments.—Certainly this regular and continuous range of oolites, with so nearly uniform an elevation of escarpment, is one of the most characteristic features of English geology, and furnishes matter for profound reflection. For, like the parallel, equally continuous and regular, and but slightly lower range of chalk, its elevation seems not at all due to local disturbances, but rather appears to indicate a general intumescence of the land in the direction of these ranges. The low vales of lias, Oxford clay, and Kimmeridge clay, which intervene between the lower, middle, and superior oolite ranges, have undoubtedly been caused, at least in part, by the erosive action of water; but to whatever extent we apply this principle in explaining the present inequality of the earth's surface, and whatever aid we receive from the established data of local elevation, these limited agencies always leave unexplained the general fact, viz., the regular altitude of continuous ranges of hills with uniformly declining planes, and no particular marks of convulsion, which overlook extensive undisturbed plains of older strata.

The vicinity of Bath, where Smith began his important researches, furnishes the general type of the lower oolite formation; and, with some modifications, the series of strata here presented, as detailed by Smith and Lonsdale, is found to be almost universally reconcilable with the phenomena of the other oolitic districts. The variations observed are principally caused by the interpolations of a larger proportion of arenaceous, argillaceous, and carbonaceous beds, so as in extreme cases to change the calcareous section of Bath into a coal field, with subordinate beds of limestone. Such is especially the case in the eastern moorlands of Yorkshire, at Brora in the Hebrides, and in the gorge of the Weser at Minden, as observed by Murchison.

The table of classification given above will make known the order of succession of groups recognized in this formation, and we shall now proceed to point out their characters and notice their variations more exactly.

Inferior Oolite Group.—The sand which is the base of the inferior oolite group in the vicinity of Bath possesses, in general, only a slight degree of cohesiveness, but in places passes into a friable sandstone. It is micaceous, of a yellow colour, and contains irregular courses of calcareous concretions called sand burrs. These nodules are often aggregated round ammonites and other organic bodies. The thickness of this bed sometimes amounts to 70 feet.

The inferior oolite varies in thickness, in some places being 60 feet, in others considerably less. The rock, according to Lonsdale, admits of being characterized in three portions. The lower one, 6 feet, hard, of a brown colour, abounds in casts of trigoniæ, limæ, trochi, &c., and is seen in many sections reposing immediately on the sand. The coated mussels, as they are termed, are found in this bed, which, in

the quarries near Bath, yields an immense abundance of species. The middle division, 10 feet, is a rubbly stone; principally consisting of crystallized carbonate of lime, through which the organization of astrææ may be clearly traced. It is, therefore, a coral bed, and, as might be supposed, is of irregular occurrence.

The upper portion of the rock, 40 to 50 feet at the utmost, contains the workable freestone or oolite of this rock. The upper part, in particular, cannot be distinguished in specimens from the great oolite above. The lower beds are more sandy, browner, and less oolitic.

The Fuller's Earth Group.—The Fuller's earth group, so named from the occurrence in it of limited beds of that substance, is a thick argillaceous deposit with a few layers of nodular limestone and indurated marl, occurring on the hill sides of Bath, and distinctly separating the inferior from the great oolite. The following is Lonsdale's summary of these beds:—

	Feet.
4. Blue and yellow clay with nodules of indurated marl.......	30 to 40
3. Bad Fuller's earth	3 to 5
2. Good Fuller's earth, brown or blue..........................	$2\frac{1}{2}$ to 3
1. Clay containing beds of bad Fuller's earth and layers of nodular limestone (Fuller's earth rock) and indurated marl	100

The Great Oolite Rock.—The great oolite rock contains, besides the more perfectly oolitic parts, which hold few shells and furnish the best freestone, a great number of beds, in which the oolitic structure is less evident or even wanting, and which are more or less filled with remains of shells, corallines, &c. These coarser portions of the rock lie at the top and bottom, and enclose the purer oolite between them.

The lower rags consist of several beds of coarse shelly limestones, 10 to 40 feet. The lowest bed of it which rests on the Fuller's earth group is fine grained and scarcely oolitic.

The oolitic beds in the middle are very variable in thickness and quality. On Combe Down the thickness sometimes amounts to 30 feet. The stone when taken from the quarry is quite soft, and holds so much water as to be beaten to a pulp by the hammer. After being thoroughly dried, it will absorb more than one-seventh of its weight of water, but by long exposure it grows harder and less absorbent. It will not stand the sea air, though in the neighbourhood of the quarries it is very durable.

The upper rags, 20 to 55 feet, consist of alternating beds of coarse shelly limestones, tolerably fine oolite sand, tough, brown, argillaceous limestone. The shelly beds were used by the Romans in their buildings at Bath, and are thought to be very durable, but are difficult to work. Some of these beds are full of millepores and other polyparia and species of echini, and a profusion of minute univalve

and bivalve shells. They often exhibit that peculiarity of internal lamination called false bedding, when the ingredients of the stone form layers inclined to the plane of stratification.

The Forest Marble Group.—The forest marble group admits of the following subdivisions in a descending order:—

6. Clay with occasional laminæ of grit	15 Feet.
And at Norton St. Philip a layer of rubbly indurated marl abounds with fragments of a small oyster and terebratula.	
5. Sand and nodules, or beds of calcareous gritstone......................	40
The sand is reddish-yellow or white, pure or mixed with clay, or lime. The gritstone, usually of a brown but sometimes of a blue colour, exists in spheroidal masses which have a laminated structure parallel to the stratification, and occasionally can be split into flags.	
The fracture often shows shining facets of interposed carbonate of lime. Organic remains are generally rare in these beds, sometimes particularly abundant.	
4. Clay with thin slabs of stone and laminæ of grit........................	10
3. Coarse oolite, or shelly limestone (forest marble) full of fragments of wood and shells, especially ostreæ and plagiostomata, bones, teeth, &c. The majority of the beds have a fissile structure, and can often be split into thin flags, or tiles, oblique to the plane of stratification.	
Thin partings of clay generally divide the beds.	
2. Sand, or sandy clay and grit	10
1. Pale blue or gray clay, enclosing thin slabs of tough brownish limestone and laminæ of calcareous sandstone or grit. Thickness variable..	5 to 40

The Cornbrash.—The cornbrash consists of numerous rubbly beds of coarse limestone, mixed with clay, altogether 10 to 15 feet thick. The beds or rather nodules are extremely irregular, and of different colours, but they are pretty uniformly composed of tough granular limestone, and abound with terebratulæ, avicula echinata, isocardia, amphidesmata, &c.

In tracing the lower oolite formation to the south from the Bath district, the inferior oolite is found to become more ferruginous (Sherborne), and with its subjacent sand to cap the lias as far as Bridport, but the great oolite soon "thins out," while the forest marble group thickens and becomes predominant. The cornbrash retains its usual characters and fossils.

Yorkshire.—In the district lying north of the Humber the lower oolitic system assumes entirely new characters, which will require separate consideration. The beds seen in the imperfect exhibition of these oolites near Cave, where they divide the lias from the Oxford clay, are the sand of the inferior oolite covered by shelly and oolitic beds, a continuation of the oolite of Lincolnshire, and above them a thin bed of pale blue clay. They are here much diminished in thickness, and, though burnt to lime, somewhat debased in purity. On

the banks of the Derwent, the lias is surmounted by the same simple series, with the addition of beds of calcareous flagstone above. Farther along the range, at Brandsby and Wiganthorpe, the series is expanded by the interposition of beds of sandstone and shale, with a thin band of coal between the sand which caps the lias and the shelly limestone which here represents the oolite of Lincolnshire. Above the limestone runs a band of pale blue clay; and upon this rests a succession of beds of sand and sandstone, enclosing spheroidal concretions of calcareous sandstone with glistening facets, often blue in the centre and full of shells, some of which resemble those of Stonesfield. Beds of sandstone, shale, and carbonaceous matter are also interpolated above this slaty rock. The oolite here is hardly deserving of that name from its lithological character; for though this appearance sometimes presents itself, the greater part of the stone is a coarse, granular, shelly limestone, with embedded shells, &c. It is, in fact, the oolite of Cave still more degenerated. The series of sandstones and shales with coal which here overlies the sandstone cap of the lias, has been supposed analogous in position to the Fuller's earth group of Bath (the similar series which overlies the limestone beds corresponds to the interval between great oolite and cornbrash), and as we proceed northwards both series increase immensely in thickness, so that the lower one reaches 500 feet, and the upper one 200; and as, from local circumstances, the coal, though never more than 16 inches thick, is worth working, these moorlands assume the appearance of a true coal field, with subordinate beds of very coarse shelly limestone. It requires, indeed, very close observation to trace the thin limestone beds across these vast moors, and amidst such a number of sandstone beds. They are best studied on the coast, and in the fronts of the bold hills over Thirsk and the vales of Mowbray and Cleveland. The coast section admits of the following summary:—

	Feet.
e Shelly cornbrash limestone of Gristhorp and Scarborough	5 to 10
d Sandstones, shales, ironstones, and coal, of Gristhorp, Scarborough, and Scalby, enclosing some calcareous shelly bands	200
c Shelly oolite of Cloughton and White Nab with clays	30 to 60
b Sandstones, shales, ironstones, and workable coal, of the Peak, Stainton Dale, Haiburn Wylie	500
a Irony sandstone and subcalcareous beds, with bands of shells and plants	10 to 60

The irony sandstone (*a*) upon the lias is a variable rock, often coarse and fragmentary, sometimes with the characters of ordinary sandstone, but generally subcalcareous, ochraceous, and full of shells and casts. At Blue Wick, near Robin Hood's Bay, it presents a double band of fossil-bearing beds, the lower ones gradually passing to the subjacent lias. The limestone (*c*) appears

with different aspects at different points. Under Gristhorp cliffs it recalls pretty exactly the oolite of Cave; but at Scarborough, Cloughton, Hawsker, Sneaton, &c., it is a very different rock, coarse, fragmentary, and mixed with veins of earthy, ferruginous, and argillaceous oolite, so as to be scarcely fit to be burned to lime. In the Stainton Dale cliffs it is a double band; at White Nab it is covered by variable sandstones, in which glistening facets, like those in the stone of Brandsby and Wittering, occur. Only one seam of coal is worked in the district, and that lies about 100 feet or more beneath the limestone. The cornbrash (*e*) appears on the coast, also, in a debased but recognizable form. The fossil plants which accompany the coal seams and sandstones (*b*, *d*) may also be detected in the limestones and calcareous slates both on the coast and at Brandsby; and it is worthy of particular attention, that both at Collyweston and at Stonesfield several of such plants occur in the slate, as brachyphylla, ferns, and cycadites. No marine exuviæ have yet been found in these coal grits or shales, but some bivalves resembling anodon, and a crustacean like cypris, which perhaps were swept down with the ferns, equiseta and cycadeæ, are found at Gristhorp. In several places a particular part of the section of lower carboniferous sandstones (*b*) exhibits the remarkable phenomenon of equiseta standing irregularly erect over considerable areas in a bed of sandstone which rests upon shale.*

This is, therefore, truly a coal field of the oolitic era, produced by the interposition of vast quantities of sedimentary deposits brought down by floods from the land, between the more exclusively marine strata of the ordinary oolitic type. We may believe this to be a case of a littoral deposit of oolite, and should naturally derive from that supposition, the debasement of quality and attenuation of thickness of the shelly limestone, in proportion as the spoils of the land brought down into the sea were more abundant. Whatever the causes were which produced these effects, they were not entirely local. The Yorkshire oolitic district is indeed the only tract yet investigated in England which exhibits these effects in a striking manner; but attentive consideration of the phenomena presented by the rag beds of oolite and coarse shelly beds of forest marble near Bath, and still more the wavy surface and vegetable fossils of some kinds of the sandstone slate of Stonesfield, and Collyweston, will lead to the conclusion that these portions of the oolitic formation were deposited within the influence of the littoral agitation of the sea, or in lagoons enjoying greater tranquillity.

Morris has lately proved that the series of argillaceous beds with plants and cyrenæ, which lie over the great oolite of Lincolnshire, are coeval with the plant beds (*d*) of Gristhorp, and like them

* Geology of Yorkshire, vol. i., 1829.

covered by the cornbrash (*e*).* This littoral or lagoon deposit is traceable in Oxfordshire, *above* the oolite which covers the Stonesfield slate.

The extensive additions of terrestrial plants and sediment are confined to the intervals between the sand which is the base, and the cornbrash which is the cap of the lower oolite formation.

The bands of ironstone on the Yorkshire coast have, for many years, yielded small supplies, chiefly gathered from the shore, to the furnaces of Northumberland. The lias bands above the ironstone, and those immediately above the oolite of White Nab, were found the most valuable. Within the last few years the lias band, often sixteen feet thick, and of good quality, has been worked with great advantage at Eston and other points in Cleveland, as well as at Gromont Bridge, in Eskdale. The area under which this bed *may* be worked measures some hundreds of square miles, with an average produce of 20,000 to 50,000 tons per acre. It dies out southwards, and vanishes about Thirsk; but there other ironstones acquire value in the oolitic series above.

The section of the strata of the Bath or lower oolite series in the Thirsk district presents the following general type:—

(Above are the Coralline oolite, calcareous grit, Oxford clay, and Kelloways rock.)

e Cornbrash, barely traceable.

d Sandstones, shales, ironstones, and carbonaceous bands, 250 feet, one layer of ironstone nodules very rich, no coal bed visible. Plants in some of the layers; fine white arenaceous freestone.

c† Calcareous oolitic and shaly beds, with layers of shells, and irony bands of different degrees of richness, not here workable, about 30 feet in all. The calcareous parts are often found to be minutely oolitic, some layers are penetrated by a calcareous crystallization, giving the "glance" aspect.

b Sandstones, shales, *ironstones*, one 3 feet bed, and several bands of nodules, all good in quality, and mostly workable, bands of *cement* nodules, one bed of *coal*, occasionally worked. 320 feet.

a Calcareous shelly partly oolitic ironstone, 7 to 12 feet thick, 20,000 tons per acre, of good quality, over it in some places shale, with a band of ironstone nodules. This is the cap of the upper lias. About 100 feet lower is a poor representative of the Eston band of ironstone, in the lias.

Scotland.—Murchison's examination of Brora and other points in Sutherland, and of the western coast of Scotland, has proved the extension of the carboniferous system of Yorkshire oolites into these northern regions, and it is interesting to observe that there, as well as in Yorkshire, the interpolations occupy the same limited space in the section.

* Geol. Proceedings, 1853.

† This group somewhat resembles cornbrash, and contains ostrea marshii, but the facts gathered in a recent survey, 1854, being carefully considered, I have no doubt of its representing the rocks of White Nab.

The following short summary of the beds in these counties will prove this point:—

Section of Brora.

Middle oolite formation consisting of........	Calcareous grit and Oxford clay.
Lower oolite formation consisting of.........	Shelly limestones representing cornbrash and forest marble. Alternations of sandstones, shales, and ironstones with plants. Ferruginous limestones, blue in the interior, with fragments of carbonized wood and abundance of shells. Sandstones and shales of great thickness in frequent alternations with plants, having *in the upper part* two beds of coal, of which the upper one is 3 ft. 8 in. thick, the lower one, not worked, 1 ft. 4 in.

Lias formation with fossils of the Yorkshire lias.

North-East Coast, Isle of Skye.

Sandstone series.
Shelly limestone.
Sandstones and shales of great thickness, with obscure impressions of plants and abundance of carbonaceous matter.
Calciferous sandstone beds, with small nodules of indurated limestone grit, with fossils and thin layers of shale with belemnites.
Blue shale (upper lias shale of the Yorkshire coast) with small blue calcareous concretions, belemnites, &c.
Sandstone with concretionary nodules and fossils of the marlstone series.
Lias shale.—*Geological Transactions, New Series.*

The same geologist has found a considerable analogy to these phenomena in the section presented by the gorge of the Weser, where that river escapes through the Porta Westphalica into the plains of Northern Germany. How unlike to the general type of the oolitic formation of the German and Swiss Jura.

Midland Counties.—Having thus produced the two most contrasted types yet discovered of the oolite formation, and by their comparison put a severe check upon the doctrine of universal formation (if such was ever entertained) among the secondary strata, it will be useful to state a few more sections of this formation in the intermediate parts of its range in England, especially of the parts which are most subject to variation. The curious fact of the continuity of the cornbrash above, and of the lower oolite sand below, from one end of England to the other, by furnishing everywhere exact limits to the formation, very much abridges the inquiry into these variations, and diminishes the chances of error. In the long range from the coast of Dorsetshire to the coast of Whitby, the character of the lower sand varies, yet not so much as is common to sandstones, the principal difference consisting in the colour which is occasioned by the degree of oxidation of the iron. Through Oxfordshire, Rutland, Lincoln, and the southern

part of Yorkshire, it is a very dark brown ferruginous rock, whence it is often called "gingerbread stone," frequently enclosing shelly concretions (Banbury), occasionally enveloping beds of limestone, and sometimes (Northampton, Rockingham) interlaminated by white beds of oolite. The quantity of oxide of iron is sometimes so considerable as to divide the mass of the rock into a multitude of ochraceous cells or "iron boxes." In some places, especially in Lincolnshire, it consists of an alternating series of white and brown sand. Ironstone (sometimes other iron ore) occurs in Northamptonshire and Oxfordshire, not only in the lias but also in the oolitic series as in Yorkshire.

With respect to the cornbrash it is sufficient to say, that though so unimportant a rock in other respects, it is probably more continuous, and more uniform in its character from Dorsetshire to the Humber, as may be seen in Smith's maps, than any other member of the oolitic formation except the sand of the inferior oolite.

Lincolnshire.—Lincolnshire presents the following section of this formation (observations made in 1821):—

e Cornbrash full of its usual fossils.

d Clay thin.
Thin shelly beds *in one locality*, somewhat resembling the blue beds of Farley near Bath.
A considerable thickness of clay ground, presumed by Smith to include the forest marble system of Wiltshire.
Sandy laminated stone, in a few localities south of Lincoln.

c Thick, apparently undivided, oolite rock, very productive of organic remains, with polypiferous beds on the top.

In the upper parts of this rock, false bedding is frequent, coarse shelly rags abound, good oolite is dug at Ancaster. This is undoubtedly the same rock as that of Cave in Yorkshire, and it is continuous with the same general character as far as Grantham, between which place and Stamford there appears to be some change.

a Inferior oolite sand.

On the line from Wandsford, through Weldon to Rockingham (1821):—

Cornbrash very distinct.
Clay of some thickness, nothing else observed.
Weldon oolite or rag, the same as the Barnack rag.
Interval, presumed to be clay, under some breadth of Rockingham forest.
Brown sand of Rockingham Hill, with interlaminated white limestones.

It might appear from these statements that the slates of Wittering and Collyweston are near the northern end of these deposits; they are unknown at present in a distinct form north of the Welland.

The following interesting table by Morris* exhibits the varying thickness of the clays, in the group between the cornbrash and great oolite of the southern part of Lancashire :—

	Essendine.	Aunby.	Dane's Hill.	Little Bytham.	Creeton.	Counthorpe.
Oyster bed and marly rock	11	0	16	8	16	5
Clays........................	9	20	6	10		4
Stem-bed....................	2½	3	2	½	1½	5
Clays........................	4	7	15	10½	10	14
Iron band....................	0	present	1	1	1	1
Oolitic rock.................	—	—	—	10	8	13

The main features of this table are recognized in all the railway cuttings north and south-west of Oxford (1854).

Collyweston Slates.—The slate of Collyweston is associated with beds of oolite and compact limestone, and presented to Murchison and the author (1831) the following detailed section :—

Local Names.	Ft.	In.	Description.
Rubble....................	4	0	Imperfectly bedded oolite.
Cale......................	4	0	Irregular and broken beds of oolite.
Bedding sand...........	1	3	Fine yellow sand indurated at top and at bottom into concretionary and slaty layers.
Broad.....................	4	0	Brown hard oolite graduating upwards to the sandy layers above. Thin beds, not burnt to lime.
Limestone...............	1	6	Hard, compact, not oolitic, containing brachyphyllum, ferns, and trigonellites.
Betch.....................	1	3	Irregular sandstone.
Slate..............	2 to 4	0	Masses irregularly spheroidal flattened, very fissile, in general calcareous grit not at all oolitic, but shelly, with littoral and terrestrial plants.
Fine sand...............			Of a yellowish colour.

The slate is quarried only in winter, for if dried by the summer sun and wind, it hardens and will not split. The holes are blocked up in spring, and the quarrymen only employed in preparation of slate. It is, in general, very equally laminated. The splitting is caused by organic exuviæ.

Stonesfield Slates.—The Stonesfield slates near Oxford have been almost universally esteemed to be of nearly the same age as these Collyweston rocks. Both are below the mass of great oolite (usually separated from it by clay), and both are above the inferior oolite. The Stonesfield slate is often assumed to be above the Fuller's earth, the Collyweston slate below it.

At Stonesfield two beds of concretionary masses, capable of being easily (with the assistance of frost) split into slate parallel to the stratification, compose with sand and friable sandstones a group five or six feet thick, under fifty feet of alternations of laminated

* Geol. Proceedings, 1853, p. 338.

shelly oolite and thin blue clay. The following is Dr. Fitton's account of the section (*Zool. Journal*, vol. iii.):—

Rubbly limestone. Clay with terebratulites. Limestone. Blue clay. Oolite. Blue clay.	32 feet.

"Rag," consisting of shelly oolite, with casts of bivalves and univalves.

The slate beds consisting of	"Soft stuff," 6 in. yellowish sandy clay with thin courses of fibrous transparent gypsum. "Upper Head," 1 ft. 3 in. to 1 ft. 6 in. sand enveloping a course of spheroidal laminated calcareous gritstones which produce the slate. These are called "Pot-lids" from their figure, and receive with the other slaty bed the name of Pendle, as characteristic of the workable stone. The stone is partially oolitic and shelly, sometimes full of small fragmentary masses. "Manure or Race," 1 ft. slaty friable grit rock.
The slate beds consisting of	Lower Head, 1 ft. 6 in. to 2 ft. sand and grit, including a course of spheroidal concretions of slate like that described above. Bottom stuff, 1 ft. sandy and calcareous grit with admixture of oolitic grains.

The floor of the slate beds is rag like the oolite above.

Most of the Stonesfield fossils, and in particular the jaws of mammalia, have been extracted from one or other of the courses of slate.

We may now return to the Bath series of oolites, and accompany Lonsdale in his survey of their extension to the northwards.

Lower Oolites of Gloucestershire.—The *inferior oolite* in the south of Gloucestershire consists of nearly equal divisions of soft oolite and slightly calcareous sand; but in the northern division of the county the latter, for the greatest part, is replaced by a yellow sandy limestone. The freestone beds, which are not to be lithologically distinguished from those of the great oolite, gradually increase in number and thickness from the neighbourhood of Bath to the Cotteswold, east of Cheltenham, where they constitute the whole of the escarpment. Murchison* gives to this rock at Leck-hampton, above Cheltenham, a thickness of 150 feet. At Lincover the beds have the under-mentioned local names:—

		Ft.	In.
Upper part.	Trigonia grit, named from the prevalent shells	4	0
	Argillaceous parting, Trigonia speciosa	0	4
	Gryphite grit contains Gryphæa, Lima, Terebratulæ	10	0
	Oolitic marlstone (Terebratula fimbria)	8	0
	Freestone	30	0
	Lower ragstone or roestone (shelly)	6	0
	Pisolite or pea grit (shelly)	4	0

This vertical importance is retained through the north of the country examined; but to the eastward of the valley, ranging from

* Geology of Cheltenham.

Stow on the Wold to Barrington, near Burford, a change takes place both in the structure and thickness of the formation. The freestone beds are there replaced by strata of nodular coarse oolite, containing numerous impressions of *clypeus sinuatus*, the sandy portion consists of only a thin bed, and the thickness of the whole of the inferior oolite group is diminished from 150 to about 50 feet.

The *Fuller's earth* loses its importance in proceeding northward, yet it was traced as a parting between the great oolite and the inferior oolite, as far as a line passing from the neighbourhood of Winchcomb to Burford, but to the north-east of this line it thins out.

Great oolite. The threefold arrangement of upper rags, fine freestone, and lower rags, into which this rock is naturally divided near Bath, does not prevail uniformly in our progress northward.

The upper rags, consisting of soft freestone and hard shelly oolite, were traced to Cirencester; but to the north-east of that town they are replaced by a rubbly, white, argillaceous limestone. The beds of the middle division become chiefly a hard oolitic limestone. At Wotton under Edge the lower rags are replaced by beds of fissile, calcareous sandstone, which run through the whole of Gloucestershire to the neighbourhood of Burford. They are extensively worked as a tile stone, possess the lithological character of the Stonesfield slate, have their fissile property in the same way developed by exposure to atmospheric agency; contain *trigonia impressa*, the characteristic fossil of Stonesfield; and on comparing the strata of Burford with those which rest at Stonesfield on the slaty beds, it was found that an almost perfect identity of character and order of position prevailed at the two localities. The Windrush quarries near Burford give the following section for comparison with that of Stonesfield previously detailed:—

Top.	Rubbly limestone	1 Foot.
	Brownish marlstone	6
	Rubbly limestone	4
	Pale sandy marl	3
	Rubbly limestone	½
	Light-coloured clay	½
	Rag and freestone	15
	Sandy laminated grit	—

Lonsdale has thus corrected the almost universal error of English geologists in classing Stonesfield slate with the forest marble, and has assigned its true place at the base of the great oolite; a most important alteration in every point of view.

The forest marble was found to possess the same characters as near Bath, consisting of a thick stratum of laminated shelly oolite, interposed between beds of sandy clay, containing laminæ of grit; and to have, from Bath to near Fairford, for its uppermost stratum, a deposit of loose sand, containing large masses of calcareous grit.

It is hardly to be doubted that the slate of Collyweston is nearly coeval with that of Stonesfield; the thick oolites of Lincolnshire comprise characters both of the great and inferior oolite of Bath. It is now ascertained that there are calcareous slaty beds above and below the great oolite; or in other words, in two or perhaps three points of the series between the cornbrash and the inferior oolite; it is known that both the great oolite and inferior oolite are subject to great variation of lithological character and thickness, and that the Fuller's earth which distinguishes these rocks at Bath is extinct, or nearly so, north of Burford.

The littoral conditions indicated by these slaty beds with their included plants and insects, are now traced very far from Brora, Skye, and Yorkshire, into the midland and southern counties, and both in the northern and midland localities traces of fresh water action occur in the carbonaceous clays which lie in the same parts of the series. Perhaps by further search in them we may yet hope to add a fourth mammalian genus to those now recognized as the oldest insectivora in the British strata.

Middle Oolite Formation.

General Description.—Very strong analogies accompany all the leading divisions of the oolitic system, and mark them as the products of a succession of similar causes. As the oolites of Bath lie enclosed between strata of calcareous sand, so those of the middle division are embedded between strata of calcareous sand and sandstone, and the association of the upper oolite with green sands at Swindon and Thame, is probably of the same intimate description. The organic fossils of all the divisions have a striking general resemblance, and the composition of the rocks is liable to similar variations.

The physical features impressed on the geography of the country which they traverse are also very similar. As the consolidated strata of the lower oolite formation form a high escarpment, which overlooks the plains of argillaceous lias; so the limestones and sandstones of this middle group rest on a bold edge, above the vales of Oxford clay, and the upper oolite rocks in the few places where they occur domineer in the same manner over the vales of Kimmeridge clay. It might have been attended with some convenience to have considered these thick clays in formations apart from the rocks, as the lias has been separated from the lower oolite, but they are from various causes so connected with them that it would have injured the practical utility of the classification.

The general characters of the surface of the middle oolite formation, are a moist valley of Oxford clay below a dry range of hills,

furnishing copious springs from the calcareous grits and oolite. Dry valleys, deep wells, narrow dells, washed by the rapid streams, occur, especially in the districts of greatest altitude, and one unacquainted with the series of formations might recognize in the general aspect of *this*, the description usually given of the lower oolite range. Outliers of the oolites and sandstones occasionally cover insulated hills of the subjacent clay, and prove the denudating power of ancient floods. The altitude of this range of oolite nowhere equals that of the lower oolite in the same region. Thus while in Yorkshire the older rocks rise in Burton Head to 1,485 feet above the sea, the later deposits reach on Black Hambleton 1,240 feet. In Oxfordshire and Gloucestershire 800 or 900 feet is the height of the lower oolite, but 400 or 500 feet that of the middle oolite.

Range and Extent.—This formation is upon the whole less continuous than the one described before, yet the discontinuity is not of the whole mass, but chiefly of the group of oolites and sandstones. These have a considerable development in Dorsetshire; first on the coast at Weymouth, and secondly, from near Sturminster to beyond Wincanton, where they produce oolitic freestone. Hence to Longleat Park they are unknown. From Longleat their range is unbroken by Westbury, Calne, Wootton Basset, Highworth, Farringdon, and Abingdon, to the banks of the Thames below Oxford. They can be traced under Shotover, and towards Brill, a few miles, but their farther course is unknown, till we arrive at the Fens, where a single point of coral rag peers up between Cambridge and Ely. From this place they are again unknown till we cross the Humber, and see the oolite and calcareous grit under the Wolds of Yorkshire near Acklam. At this point emerging from beneath the chalk, they encircle the vale of Pickering by Malton, Helmsley, Pickering and Scarborough, increase greatly in importance, and assume more completely than in any other part of England, excepting perhaps Weymouth, the full characters of their formation. But while the oolitic group is thus dismembered into four widely detached regions, the Oxford clay beneath is as remarkably connected from the north side of the Dorsetshire downs, by Wincanton, Melksham, the Vale of the Isis, Ottmoor, the Vale of Bedford, Huntingdon, the western border of the Fens, and the vale between the Cliff and Wold ranges of Lincolnshire to the banks of the Humber. Beyond the unconformity of the chalk wolds, which here conceals all the oolites, its course is narrow, but undivided, beneath the slope of the calcareous grit round the Vale of Pickering to Scarborough.

We shall now offer a few details of the internal structure and variations of these rocks.

The *clay* below the Kelloway rock has been very little noticed, and is indeed not very important. It occasionally contains phola-

domyæ and shells near Bath, and more frequently abundance of selenite, and on the coast of Yorkshire has yielded some curious remains of crustacea. As for the greater part of the range of the Oxford clay the Kelloway rock is unknown, this clay can seldom be distinguished. In Yorkshire it seldom exceeds a few yards, and generally is less than three feet in thickness.

Kelloway Rock.—The Kelloway rock, so named by Smith from Kelloway Bridge in Wiltshire, which is one of the few places where it occurs in the south of England, is in that county more remarkable for the beauty, peculiarity, and abundance of ammonites, gryphææ, and other organic remains which it produces, than for either its thickness or continuity. It is there a calcareous sandstone, appearing, when devoid of organic remains, very similar to those which accompany the coralline oolite, externally brown, internally gray or blue, of a rubbly nodular structure, altogether less than twelve feet thick. From Wiltshire to Northamptonshire no mention is made of this rock, but it was found with its usual fossils at Boziate Hill, near Wellingborough, by the writer of this volume, in company with Mr. Smith, in 1820.

In 1821, the same observers established the occurrence of the Kelloway rock at Hackness and Scarborough on the sea-coast of Yorkshire. It is coextensive in that county with the range of the Oxford clay, from under which it rises into an escarpment. It arrives sometimes at a thickness of sixty feet, and is then locally distinguishable into several portions. It is, however, altogether a mass of sand and calcareous sandstone, with or without organic remains; the upper beds very thick, indurated by admixture of oxide of iron, and multitudes of gryphææ, belemnites, ammonites, and aviculæ, and other fossils. Not unfrequently in the vicinity of the shells it becomes sufficiently calcareous to assume the character of a sandy oolite, sometimes ferruginous like that of Dundry. The sandy parts of the mass are often variously stained brown, reddish, yellow, or remain perfectly white, in layers or irregular stripes, and traversed by dissepiments of oxide of iron. In a very few places it is useful as a building stone.

There is perhaps no more curious fact on record than the occurrence of this apparently indefinite rock, with almost identical characters, after so great an interruption of continuity.

Oxford Clay.—The Oxford clay (clunch clay of Smith) appears, in the whole of its range south of the Humber, a pale blue clay, turning yellow on the surface, with large sparry septaria, and some layers of chocolate-coloured shale (Tytherton), with ammonites and other fossils. In Yorkshire, it is less tough, and more generally arenaceous, gradually changing in quality to the Kelloway rock below, and the calcareous grit above. Most of the organic remains which it yields

belong to the lower part of the stratum, and are in general identical with, or very similar to, those of the Kelloway rock. Taken in general terms, the suite of fossils at Weymouth belonging to the Oxford clay is considerably allied to that of the Kelloway rock and Oxford clay of Yorkshire, but further comparison of the species of ammonites is yet needed. In the Museum at Strasburg fossils of the Kelloway rock, as well as of the Oxford clay, are recognized.

It is painful to observe the dreadful waste of money in ill-advised trials for coal along the line of the Oxford clay. The least fragment of jet or morsel of bituminous shale, especially if accompanied by "blue metal," is enough to make a credulous proprietor listen to an ignorant collier, and throw away the value of his solid land in sinking for the imaginary treasures beneath it.

Coralline Oolite Group. — Lower Calc Grit, Wilts, &c. — The lower calcareous grit should be carefully distinguished from the iron sand, with which Smith has occasionally confounded it, nor is the distinction difficult, for, independent of its geological position, the calcareous grit is not particularly ochraceous, except in a single bed or so, as at Hackness and Scarborough, and never assumes that dark ferruginous aspect so remarkable in the other rock. In Wiltshire, where it was first observed, it appears as a thick stratum of sand, enclosing irregular beds of sandstone, or of calcareous grit, which assumes the aspect of coarse limestone. These sandstones are brown externally, but gray or blue within. Irregular layers of clay occur in places, and friable beds of decomposed shells. The prevailing colour of the sand is yellow, but sometimes it is ash-coloured. At Studley, near Oxford, Dr. Buckland detected a peculiar bed of clouded gray colour, and very tough and dense texture, a sort of argillaceous chert, rich in pinnæ, ammonites, and other organic remains. It probably belongs to the lower part of the rock.

The calcareous grit of Heddington, also rich in organic remains, ammonites, belemnites, plagiostomata, pectines, &c., is a very coarse rock, with an abundant admixture of quartz pebbles, chiefly of small size, and fragments of shells. It forms irregular beds and concretions in beds of quartzose sand, mixed with calcareous matter.

Professor Sedgwick's description of the calcareous grit of Weymouth makes us acquainted with a more complete series than that of Wiltshire and Oxfordshire. The following statement of beds there is in the descending order:—

e Yellow sand like *b*, with beds of calcareous grit in the upper part.
Beds of oolite succeed.
d Blue argillaceous beds, alternating with hard compact beds with an even fracture.
c Strong ferruginous jointed beds of calcareous grit.
b Thin beds of yellow sand and sandstone.
a The lowest beds upon the Oxford clay are black, and meagre to the touch, filled with irregular branching stems like alcyonia.

Lower Calc Grit, Yorkshire, &c.—The section of the lower calcareous grit on the Yorkshire coast between Filey and Scarborough has a striking resemblance to that of Weymouth. Immediately on the Oxford clay rests a series of gray marly sandstones, 70 feet thick, gradually becoming more yellow and more consolidated upwards, till they assume the harshness which belongs to stones usually called cherty. This cherty bed appears to correspond with that mentioned before at Studley. It continues across the moors to Hambleton. Above these runs a band of yellow sand, 9 feet thick, enclosing large spheroidal highly indurated calcareous balls. This band is traceable through the interior, where it forms rabbit-warrens, as far as Whitestone Cliff, and there the balls are of immense size. When they fall out, the rock looks cavernous. The upper part of the rock consists of strong beds of calcareous sandstone, very remarkably covered on the surface, and also penetrated by branching cylindrical bodies, which continually remind us of sponges or fucoids. The upper beds of this series are of a redder colour, and more calcareous than the others, remarkably full of shells, and in some places alternate with two or three beds of oolitic limestone also shelly. In the interior of the moors, they are often used for wallstone. It is not always quite easy to draw the line between them and the oolite above, especially when the latter is unusually shelly, and no coral bed intervenes.

According to Lonsdale, there is in Wiltshire a pale blue clay, 10 feet thick, interposed between the lower calcareous grit and the coralline oolite.

The coralline oolite, or coral rag group, as described by Smith, Conybeare, and Lonsdale, near Oxford, Wootton Basset, and Bath, seems not so complete a series as that described by Professor Sedgwick at Weymouth, and by other authors in Yorkshire.

Weymouth.—The thickness of the whole group is greater in Yorkshire than elsewhere, but nowhere in that country exceeds 80 feet. The section at Weymouth gives above the calcareous grit the four following groups:—

i Thick limestone series, at the bottom of which lie masses of coral rag, containing thecosmilia annulata, astrææ, &c. with innumerable fragments of trigonia clavellata. In the higher portion are many meagre sandy beds, nearly resembling the lower calcareous grit, but more calcareous, and with a finer suite of organic remains.

h Beds of impure sandy oolite, containing besides other fossils, a few specimens of ostrea deltoidea.

g Thin beds of oolitic marl, containing innumerable specimens of the small clypeus clunicularis, casts of melaniæ, &c.

f Many beds of pure oolite with beds of argillaceous partings, alternating with other shelly oolitic beds, somewhat resembling forest marble. In some of these beds the oolitic particles are associated with a variety of marl, and are incoherent.

Coralline Oolite, Wiltshire.—Lonsdale describes the Wiltshire coral

rag in three divisions, which do not succeed one another in any certain order, but rather intermix with and replace one another. One of them, from which the formation takes its name, is an irregular mass of nodules mostly crystallized, but sometimes earthy, and connected together by pale bluish clay. These nodules consist of little else but corals of the genera isastræa, thecosmilia, and comoseris, especially the former, which sometimes separately compose the whole mass. The lower part of this bed sometimes affords a dark blue crystalline limestone.

Another form of the rock is found in the oolite of Calne, which consists of alternations of hard shelly oolite used for flags, and soft, perishable, scarcely oolitic, limestone, workable by sawing parallel to the beds.

This form of the rock passes into the third or rubbly oolite, which is the most abundant variety in Wiltshire. This is a nodular rock with very indistinct stratification and much irregularity of texture, occasionally with ova three-tenths of an inch in diameter, constituting what is called pisolite.

In the deep pit through Kimmeridge clay on the line of the Wilts and Berks Canal, this rock was very thin, scarcely oolitic, but chiefly a cellular mass of caryophylliæ and astrææ, and a similar character prevails in some quarries in the neighbourhood of Wootton Basset. Below it the lower calcareous grit was in the state of loose sand.

Oxfordshire.—Conybeare divides the coralline oolite near Oxford into two parts, of which the upper is a calcareous freestone of close texture, full of comminuted shells, and irregularly oolitic or pisolitic. The beds are very thick, and the stone has been much used in buildings at Oxford, but is not found to be durable. The lower part is the true coral rag, consisting of two or three courses of nodular rubbly rock, very crystalline in aspect, and composed of masses of isastrææ and thecosmiliæ, with admixture of echinital and shelly fragments.

Yorkshire.—In Yorkshire the lower beds of the coralline oolite are in general exceedingly shelly, and full of clypeus dimidiatus, clunicularis, &c., and on the north side of the Vale of Pickering, at Hackness, Ebberston, &c., are marked by an irregular bed of coral (isastrææ) and sponges. The middle part of the rock is regularly bedded with thin partings of clay and very large vertical joints. The different beds vary much in the same quarry, from a soft, loose, whitish oolite to a solid rock with blue centres and large pisolitic spherules. At Malton it is more uniformly oolitic, and very full of chemnitziæ, trigoniæ, plagiostomata, &c., and organic remains of all kinds. Near the upper part in the Ayton quarries is a bed of thecosmiliæ and echini; and the rock is crowned at Sinnington, Helmsley, &c., by a bed filled to excess with turritellæ and chemnitziæ.

Chemnitzia striata and turritellæ occur near the top of the rock about Brompton and Hackness, but at Malton they lie indiscriminately. Ammonites chiefly belong to the lower beds. About Kirkdale and Helmsley layers of obscurely defined nodules of bluish-gray chert, having the texture of sponges, lie in the lower part of the rock, and remind us of the siliceous sponges of the Portland oolite.

These sections will show at once the general accordance of the characters of this irregular oolite, its variable thickness, and indefinite order of succession, circumstances which belong indeed more or less to all the oolitic formations. The corals which characterize the rock lie very unequally, yet perhaps we may perceive a tendency to form two layers, one near the top, the other at the bottom of the rock. The Oxford series seems imperfect by the deficiency of the upper members, a circumstance probably connected with ancient denudations, by which also this rock has been greatly affected in different parts of Yorkshire.

Upper Calc Grit.—The upper calcareous grit, obscurely indicated at Weymouth, and very thin and unimportant in Wiltshire (where it appears separated from the oolite by ferruginous clay), is of considerable note along the north side of the Vale of Pickering, especially about Helmsley and Hackness. It then reaches even a thickness of 60 feet, and by intercalating its upper part with the Kimmeridge clay establishes a transition from the middle to the upper oolite formation. It is in general more ferruginous and less cherty than the lower calc grit, and in Yorkshire contains apparently fewer organic remains, but of the same kinds. It has been entirely removed by denudation from the oolite cliffs of the coast. At Weymouth its fossils are numerous and fine.

Upper Oolite Formation.

The upper or Portland oolite formation, consisting of limestone above and clay below, might be expected to occupy a country whose physical geography should strongly resemble that of the district of coralline oolite. The area occupied by the calcareous group is indeed so very small in England, that little can be said on this point concerning it. Its commanding appearance in Portland Isle, in the Vale of Pewsey, at Swindon, and in the Vale of Aylesbury, is analogous to that of the oolitic rocks in general, and the sands with which it is in some places associated, increase this resemblance.

Kimmeridge Clay.—The Kimmeridge clay in its much longer and more connected range in Dorsetshire, Wiltshire, Berkshire, and Buckinghamshire (where, though growing thinner, and with diminishing area, it can be traced at least as far as Little Brickhill), and

beneath the wolds of Lincolnshire, and through the Vale of Pickering in Yorkshire, presents the usual characters of a thick clay deposit, broad vales with a cold, stiff soil, without springs.

The Kimmeridge clay, at its typical locality in the Isle of Purbeck, appears in the cliffs as a laminated clay, bluish or grayish-yellow, dividing spontaneously like other shales into large tabular masses, the joints often lined by calcareous spar. Layers of small argillaceous nodules occur. It passes gradually into a bituminous shale, imperfectly combustible, and finally into layers of brown shaly coal, of specific gravity only 1·319, which burns with a smoky yellowish flame. Alum was formerly manufactured from these shales. The group is supposed to equal 600 feet in thickness. (*Geology of England.*) Insects have been found by Brodie in Kimmeridge clay. In the Vale of White Horse at Even Swindon, it was penetrated by a well to the depth of 233 feet, and the additional thickness of the incumbent beds in Swindon Hill being taken at only 70 feet, the stratum will appear 300 feet thick. Near Oxford it is only 100, and at Bagley Wood was found only 70. In Lincolnshire and Yorkshire its thickness generally appears much less through the unconformity of the chalk strata.

Near the bottom of the Kimmeridge clay in the Vale of White Horse, *below* the layers of ostrea delta, was found a band of coarse oolitic ironstone with fossils, and besides this occurred layers of septaria, with ammonites, trochi, and many other fossils much allied to those of the coralline oolite. Shale and bituminized wood were found at about the middle of the clay, and above this a course of thin balls of stone with mineral water. Near Weymouth the lower part of the clay contains, *above* large beds of ostrea delta, beds of ferruginous impure calcareous grit, partially oolitic, and alternating with beds of red and green sand and blue clay containing ostrea delta. Small bands of calcareous grit may be seen in the lower part of the Kimmeridge clay of Yorkshire, below layers of ostrea delta. It thus appears that the remarkable species of oyster so named by Mr. Sowerby is a very characteristic fossil of the lower parts of this clay group, and its manner of occurrence is equally so. For whether in Yorkshire, at Helmsley, Kirkby Moorside, Elloughton, &c., in Lincolnshire at Market Rasin, at Little Brickhill in Buckinghamshire, at Heddington near Oxford, at Even Swindon and Pewsey Vale in Wilts, or at Weymouth, and we may add, from personal observation in 1829, at Havre, it always appears in broad continuous floors, parallel to the planes of stratification, the valves usually together, with young ones occasionally adherent to them, and entirely embedded in clay, without nodules or stones of any kind, and without any other organic remains in the layers.

Portland Oolite, &c.—The upper oolite group consists, like those

previously described, of a variable mass of sand and sandstone concretions, surmounted by a partially oolitic, shelly limestone. Were the rock to be seen more completely, it is probable that it would also show a less definite arenaceous zone above. In Purbeck it is covered by the fresh water or Wealden formation, and in Wiltshire, Berkshire, and Buckinghamshire by a feeble representative of the Wealden, or by the lower green sand.

The varieties of composition in the limestone are such as have been noticed for the other oolites, *viz.* fine grained white oolite, loose granular limestone of earthy aspect, and compact cretaceous limestone with conchoidal fracture.

In the Island of Portland the groups present, according to Webster (*Geological Transactions*), the following characters:—

Upper beds	*Stone brash*, a cream-coloured limestone	3 Feet.
	Parting of the same with black clay	1
	Cap stone, in three layers with partings of clay cream-coloured and hard, so as to turn the points of the tools.	10
Middle beds	*Roach*, a rock composed of fragments of oyster shells cemented together	6
	White beds, marketable stone	5
	Layers of flint and stony rubbish	6
	Middle bed, marketable stone, with few marine impressions	5
	Parting stone with shells of no value	2
	Third bed with few shells, generally the most saleable freestone	7 to 14
Lower beds	Many layers of flints and of unserviceable stone	50 to 60

Still lower, according to Buckland and De la Beche, is a bed of sand and sandstone 80 feet thick, with green grains, and very like to the lower green sand.

At Chicksgrove, in the Vale of Tisbury, Wilts, the series of limestones, more or less associated with sand, especially in the lower part, reaches more than 60 feet in thickness. Miss Benett, who has extracted so many treasures from those quarries, has given a minute section of the beds.

The five upper beds, amounting to 29 feet, consist of white limestone, locally called chalk, with one interposed layer of bad shelly stone, and a band of cherty flint 4 inches thick. The middle bed of this limestone, 2 feet thick, is excessively rich in shells, but the thicker beds above and below contain none.

The next three beds of the quarry, amounting to 10 feet, consist of sandy limestones, with fragments of shells.

Five beds below consist of sandy limestone, mostly compact and shelly, with grains of green sand in greater or less abundance.

The three lowest beds are composed of loose sandy limestone, with more or less of the green grains before noticed, shells and fragments of shells.

The shells most abundant at Chicksgrove are trigoniæ, pectines, ammonites, cardia, trochi, &c.

Brill, &c.—The imperfect sections at Brill Hill and Garsington present several points of analogy with the above section, especially in the presence of the cretaceous bed, and the quantity of sand below the calcareous part of the rock is well seen here and at Shotover, where it encloses in the lower part large, grotesque, concretionary blocks of sandstone, sometimes full of shells, and generally abundant in green grains.

Abundance of green grains accompany these lower beds in their course through the vale of Aylesbury, and are also recognized at Swindon.

The height of the ground occupied by the detached portions of the upper oolite group is considerable in Brill Hill, (780 feet,) in Shotover amounts to 583 feet, at Swindon probably 400 feet, in Portland 300 feet, but in the Vale of Pewsey it is very low.

Dirt Bed of Portland.—One of the most interesting observations concerning the circumstances which intervened between the marine deposits of oolite and the fresh water or estuary deposits of the Purbeck clays and limestones, is that of Buckland and De la Beche on the *dirt bed* which lies between these groups of strata in the Isle of Portland. This bed is compared by those acute geologists to black vegetable mould. The stems of cycadeæ and larger coniferæ, which are found in this bed, often "stand erect, and have their roots attached to the black soil in which they grow;" thus presenting us with an ancient submerged forest, for comparison with the more modern submarine forests which in so many points margin the English, Welsh, Scotch, and Irish coasts.

It is concluded by these authors that the Portland rock, whereon these plants are stated to be in the place and attitude of growth, had been raised to become dry land, and then sunk again, under such circumstances as to become covered by fresh water, which produced the Purbeck limestones and clays; and it appears a matter of probable inference that at the same periods the whole Wealden district was submerged under nearly the same circumstances. The absence of conglomerates and dislocations appears to prove that these submersions were effected quietly and gradually: certain beds of oysters show that the waters were at least occasionally brackish, the sea again regained its dominion, and deposited the cretaceous rocks and marine testacea, and finally yielded place again to a lacustrine deposit.

Wealden Formation.

Until the appearance of Mantell's excellent works on the geology of Sussex, the peculiar relations of the vast thickness of sandstones and clays of the interior of Kent, Sussex, and Hampshire, were mis-

understood. No one supposed that these immense strata were altogether of a peculiar type, and interpolated amidst the rest of the marine formations, as a local estuary formation, of which only very faint traces can be perceived in other parts of England. Always striving to make particular results harmonize into one general system, Smith and other geologists at one time referred the interior sandstones to the "iron sand," and the Weald clay to one of two beds, confused under the title of oak-tree clays. This mode of classification seemed, indeed, tolerably consistent with the mineralogical characters of the formations, but was found wholly at variance with their animal and vegetable remains. For these, instead of being fossils of the iron sand and Kimmeridge clay or gault, were really a peculiar suite of terrestrial and fluviatile exuviæ of which very few traces have been perceived elsewhere.

Mantell's publications, followed by many other writings, have clearly shown that the true place of the strictly Wealden formations is *below* the iron sand or lower green sand, and immediately *above* the Purbeck limestones, which overlie the Portland oolite.

The only places in England where analogous beds are known to occur, are at the back of the Isle of Wight, in the Isle of Purbeck, along the south side of the Dorset Downs, in the Vale of Tisbury in Wilts, and below the range of the chalk hills of Berkshire and Buckinghamshire.

Groups.—The Wealden formation naturally divides itself into two groups, which give distinct physical features to the countries which they occupy: and if to these we add the Purbeck limestones below, we have the following order of succession:—

Upper group. Weald clay.	Pale blue clay, of considerable but variable thickness, having in the upper part septaria of argillaceous ironstone, and in the lower part beds of the shelly limestone, called Sussex marble.
Middle group. Hastings sands.	Fawn-coloured sand and friable sandstone. (Horsham beds.) Calciferous sandstones, alternating with friable and conglomerate grits, resting on blue clay. (Tilgate beds.) White sand and friable sandstone, alternating with clay. (Worth sandstone.) Bluish-gray limestone alternating with blue clay and sandstone shale, and some beds of calciferous sandstone. (Ashburnham beds.)
Lower group.	The Purbeck beds, consisting of shelly limestones alternating with clay.

The Weald clay forms one general valley, most conspicuous on the northern side, between the elevated central ridges of the Hastings sands, and the chalk downs of Kent, Surrey, Hampshire, and Sussex, from Hythe by Tunbridge, Hartingcombe, Hailsham, to Pevensey.

The Hastings sands distinguish themselves by forming a central axis of elevation along what is called the Forest ridge, by Battle,

Crowborough, and Tilgate Forest to Horsham: Crowborough, the highest point, is 804 feet above the sea. This arrangement may be studied on Mantell's and Smith's sections, but the general axis of elevation is so confused by a number of local disturbances, and is, moreover, so broad a ridge, that its character is often overlooked. Those who suppose the chalk of the northern and southern escarpments to have once extended over all the area of the Wealden formation, and to have been subsequently removed by watery violence, have rightly applied to this devastated region the name of the great denudation.

A decided analogy prevails between the upper part of the Purbeck series and the marble beds of the Weald clay. We shall now add a few details on these groups in succession, beginning with the Purbeck beds.

Purbeck Beds.—These consist of many thin strata of argillaceous limestone, alternating with slaty marls, and form an aggregate of 300 feet in thickness. Webster describes the beds of stone as consisting chiefly of shells, usually, and with much probability, referred to the fresh water genus paludina. A small portion of these calcareous beds is fit for columns, chimney-pieces, and other architectural uses, for which the "Purbeck marble" is celebrated. Our cathedrals were formerly supplied from quarries in the very highest part of the series, which are now extinct. The shells in this stone are usually *small* paludiniform shells. According to Mr. Middleton three *veins* of good stone, not exceeding altogether 17 feet, lie in the midst of alternations of other stone compact or shelly, and black slaty clay, more than 270 feet thick.

We are indebted to many geologists, following the indications of Webster, for notices of the strata of Purbeck, and the district has now been surveyed by the geologists who follow the standard of De la Beche. To Dr. Fitton's enumeration of the fossils of the fresh water beds, Professor Forbes added a large series of newly discovered forms, and described the curious circumstances by which they are accompanied.

The lowest Purbeck *fresh water* beds, 8 feet thick, appear *suddenly* upon the Portland *marine* beds. They contain *Cyprides*, *Valvata*, and *Limnæa*. Above these is the great dirt bed, with stools of *Cycadeæ;* another dirt bed occurs above; cypridiferous shales follow.

Twenty or thirty feet of shales, laminated marls and limestones, with occasionally siliceous bands, follow, filled with Ripoæ and small Cardia, the denizens of *brackish water*.

Purely *fresh water* marls come on above with the same groups of fossils as those below.

Greenish shales with Zosteraceæ and *marine* shells succeed.

New fresh water beds succeed, with *Cypris*, *Valvata*, *Paludina*, *Planorbis*, *Limnæa*, *Physa*, and *Cyclas*, all different from what were seen below. *Gyrogonites* occur here in cherty stone.

Next above is the cinder bed, full of *Ostrea distorta;* here occurred *Hemicidaris Purbeckensis*, and a *Perna.*

Mixed marine and fresh water beds succeed, with fishes, reptiles, &c.

Then followed a more decided sea inroad, with *Pectens*, *Modiolæ*, *Aviculæ*, and *Thraciæ*, all undescribed forms.

Brackish water strata full of *Cyrenæ*, with bands of *Corbulæ* and *Melaniæ*, are next in order; cyprides, turtles, and fish, crown these bands.

Lastly, a third series of fresh water strata commence with a new series of fossils, *Cyprides*, *Paludinæ*, *Physa*, *Limnææ*, *Planorbes*, *Valvatæ*, *Cyclades*, *Uniones*, and fish. These continue till they merge into the base of the Hastings sands.

So similar to living species are the fresh water shells of Purbeck, as to be hardly distinguishable from them. The whole series is about 155 feet thick.* These deposits have yielded many insects, fishes, and reptiles, and one mammal, *Spalacotherium.*†

Ashburnham Beds.—The Ashburnham beds, above 100 feet thick, consist of shelly limestone and shale, alternating with blue clay, and containing subordinate beds of ironstone and sandstone. Limestone, of a dark bluish-gray colour, full of immense quantities of bivalve shells, more or less spathose, is the most characteristic deposit of the group. The shale which is associated with this limestone, sometimes contains the same shells in a white friable state. In ancient times the rich ironstone accompanying this limestone was, through the use of the latter as a flux, converted into iron by wood fires, and thus, in part, have the vast forests of Sussex been diminished. The shells are usually supposed to belong to cyrena or cyclas, in accordance with the opinion that the whole Wealden formation is of fluviatile or estuary origin At Poundsford a bed of calciferous Tilgate sandstone is found *under* a bed of the Ashburnham limestone, and the same was found in some of the limestone pits of Lord Ashburnham.

Worth Sands.—The Worth sands and sandstones afford a fine soft building-stone, extensively dug at Worth, near Crawley. The sandstone is for the most part of a white or pale fawn or yellow colour, and occasionally contains leaves and stems of ferns, arundinaceous plants, and other vegetable reliquiæ. They may be well studied in the cliffs near Hastings.

Tilgate Beds.—The Tilgate beds consist of three divisions. The lower one is clay or marl, of a bluish-gray colour, alternating with sand, sandstone, and shale, and containing stems of vegetables, and very rarely bones and shells.

The middle division consists principally of large concretional or lenticular masses of a compact calciferous grit, or sandstone lying in sand. The stone is fine grained, of a light gray colour, inclining to blue or green, and is composed of sand, cemented together by about

* Forbes in Reports of British Association, 1850, pp. 79–81.
† Owen in Geological Journal, 1854.

25 per cent. of crystallized carbonate of lime. Its fractures frequently show glistening faces. The lower portions of this bed form a conglomerate, and contain *pebbles* of quartz and jasper, sometimes *evidently* water-worn. (Of this stone are three or four layers, from 2 or 3 inches to $1\frac{1}{2}$ or 2 feet, associated with sand.) The surface of the blocks is often covered with mammillary concretions. These are the strata from which Mr. Mantell has drawn the astonishing profusion of animal and vegetable remains. The vegetables are wholly of terrestrial origin, mostly of cryptogamous and gymnospermous structure. There are probably no zoophytic remains. The testacea (mostly casts) much resemble the lacustrine genera, paludina, unio, cyrena. Fish teeth and scales abound, with remains of a land tortoise, a fresh water and a marine turtle, plesiosaurus, crocodile, megalosaurus, hylæosaurus, iguanodon, and some kinds of aquatic birds.

Irregular alternations of sand and sandstone, of various shades of green, yellow, and ferruginous, the surface often furrowed like the sand on the sea shore, cover the whole group.

Horsham Beds.—The Horsham beds of sand and friable sandstone, gray, yellow, or ferruginous, with occasional interspersions of ironstone, and a very large proportion of disseminated small linear portions of lignite, form the upper division of the Hastings group, and encircle the immense Tilgate beds. The sandstone is micaceous and ferruginous, and sometimes holds a considerable proportion of calcareous matter. These beds alternate with a stiff gray loam or marl. The lignite is conjectured to have been derived from carbonized ferns.

Weald Clay Group.—The Weald clay group, besides its general physical features already mentioned, has little to detain us. The septaria of this clay are composed of a deep red, argillaceous ironstone, and with remains of fishes and cyprides, occur in layers of two or three feet in thickness in the upper divisions of the clay. The shelly limestones, so well known by the name of Sussex marble, appear to occupy chiefly the middle beds of the Weald clay. They occur in layers of a few inches or a foot in thickness, separated from each other by seams of clay or coarse friable limestone. The compact varieties, when polished, exhibit sections of the enclosed shells. These are usually referred to paludina, and have been compared to the recent paludina vivipara, and they are associated with the shelly remains of a minute branchiopode, (cypris,) from which circumstance it is inferred that the Weald clay is a lacustrine deposit. This shelly marble occurs all along the line of the Weald clay from Leighton to Petworth, Newdigate, South of Tilvester hill, and Bethersden in Kent: potamida? and cyrenæ have been collected from this clay. Insects have been found in it by Messrs. Binfield.

Fresh Water, Origin of.—The evidence upon which it is now very generally admitted that the Wealden formation was a fresh water or estuary deposit, is founded upon a contemplation of the organic remains, and this subject admits of three general observations.

First. There is in all the strata of the Wealden formation, whether sandy, argillaceous, or calcareous, an almost entire absence of decided marine genera of shells and zoophyta. In particular, the numerous and characteristic tribes of ammonites and belemnites, of trigoniæ, terebratulæ, and ostreæ, of echinida, stellerida, and polyparia, are entirely absent from almost every bed, a circumstance certainly unparalleled in any section of equal variety among marine strata.

Secondly. What shells there are have most generally the forms of fresh water or littoral genera, and it may be remarked especially that this kind of evidence bears with equal force upon all the groups.

Thirdly. The plants which abound in this middle group are of terrestrial, or marshy, and not of marine origin, and the saurian remains also indicate the littoral or marshy life of those monstrous animals. The recently discovered land mammal, Spalacotherium, cannot be admitted in evidence.

We may therefore confidently adopt Mantell's conclusion of the fresh water origin of the materials of the Tilgate beds, and suppose these materials to have been deposited in an estuary by one or many rivers; the lower beds of limestone and clay, and the upper group or Weald clay appear to demand partly limestone and partly brackish, rather than marine conditions. The *materials* of these argillo-calcareous deposits were also derived from the land, but not by the same processes or in the same manner as the arenaceo-calcareous deposits of the forest ridge. Whatever may have been the causes, it is probable that the change from the *truly marine* Portland oolite to the partially *lacustrine* Purbeck beds was not the fruit of a violent convulsion, but the result of easy and even intermittent operations, such as general vertical movements of the sea bed might bring about. In a great part of the oolite deposits we find traces of a neighbouring land; in several the phenomena of fresh water lagoons, opened at intervals to the sea, in others, the deposits of great rivers filling up an estuary. We require nearly all the varieties of alternating sea and fresh water action to understand the great Wealden formation.

Oolitic System.—Foreign Localities.

Range and Extent.—The oolitic system is so largely developed in England as to form a very conspicuous, if not the principal feature in its physical geography, and its extreme ramifications reach the northern and western coasts of Scotland and the eastern shore of

Ireland. But the range of these rocks is still more extensive on the continent of Europe, and indications of the continuation of the lower formation of lias occur in North America and are repeated in India. In France a broad belt of oolitic rocks borders on the east the primary rocks of Brittany and La Vendée, and sweeps round the basin of Paris from the coast of Normandy (Calvados), by Falaise, Alençon, Lemans, Saumur, Poitiers, Chateauroux, and Nevers, and through Burgundy, Franche-Comte, and Lorraine, till, along a line from Avesnes to Luxemburg, it abuts against the slate mountains of the Ardennes. From Poitiers the oolites continue themselves westward to La Rochelle, southward to Angoulême, Perigueux, Cahors, and the vicinity of Montauban. A little discontinuity here occurs; but the oolites of Rhodes and the Cevennes mountains, by prolonging themselves south-westward to Montpelier, Carcassone, and Foix, along the northern slope of the Pyrenees to Fontarabia, and north-eastward to Montelimart and Grenoble, and so to the Jura, and south-eastward to Marseilles and Nice, unite into one irregular mass the whole area of the French oolite. These formations are largely developed in Spain, and, in particular, form a band on the slope of the Pyrenees.

Along the Swiss border of France runs the long calcareous chain of the Jura, and this whole mountain region is a mass of the oolitic rocks. It is therefore generally assumed on the continent as a type of the system; and the terms Jura-kalk, Jura formation, are exactly equivalent to our oolitic system. This is connected below the alluvial valley of the Saone with the oolites of Burgundy. In its continuation northward, the Jura ranges pass in a broad belt through Wurtemberg, Bavaria, and Franconia, and reach the Maine as it issues from the Bohemian mountains.

The Jura is also connected, by crossing the Rhone below Geneva, with the limestone which follows the range of the Western Alps from Provence through the Tarentaise and Savoy into the Valais, and continues along the Oberland mountains, across the Lakes of Thun, Brientz, Lucerne, and Wallenstadt, and then beneath the Tyrolese and Styrian Alps, by Inspruck and Salzburg to the neighbourhood of Vienna. Nor is this the end of the enormous range, for the northern border of the Carpathians about Cracow and Dynow is defined by vast breadths of compact oolite.

On the southern side of the Alps the same limestones appear in great force, and stretch through Illyria and Carniola to Trent, and the Lakes Guarda, Iseo, Como, Lugano, and Maggiore.

Besides these immense ranges of rocks of the oolitic era, many smaller detached portions may be seen upon Von Buch's and other maps, and one in the northern part of France, around Boulogne, is of particular interest, in connection with our Wealden.

It appears, then, that the sea which deposited the oolites floated round, or perhaps covered the spaces where now rise on high the Alps, the Carpathians, the Pyrenees, Auvergne, the Vosges, the Black Forest, and Bohemian mountains, in general corresponding to the basin in which the saliferous system was formed. The original arrangement of the rocks has been in places immensely disturbed, and vast regions have been devastated by floods, yet no doubt the general geographical outlines of the system are nearly what they always were. It may not be easy always, in the present state of knowledge concerning the extent of subterranean movements, to say what were the depths and the shallows of this great ocean; but even toward this very considerable approximations may be made by comparing the mineral, and zoological, and botanical characters of the deposits in different places.

Divisions of the System.—Notwithstanding their vast extent, it does not appear that the continental oolites are anywhere subject to greater variation of composition than the English series.

In the north of France most of the groups acknowledged by the English geologists may be recognized, as the lias, inferior oolite, Bath oolite, forest marble, Oxford clay, coralline oolite, Kimmeridge clay, and even the Portland oolite and Wealden (De la Beche, *Geol. Trans.*), and the organic remains are either very similar or identical. But in the vicinity of the granites of Auvergne, it is difficult to distinguish more than the lias, and one great overlying mass of oolites indistinctly divided, except by having in the lower part a ferruginous bed sometimes accompanied by ferruginous sand probably corresponding to that of the inferior oolite.

The Jura shows us distinctly the lias, and a mass of calcareous rocks, sometimes perfectly oolitic, in other places earthy or compact, occasionally interlaminated with clays, but hardly capable of any clear and satisfactory divisions. The lower parts are often ferruginous and sandy, and clearly represent the inferior oolite. The upper parts, nevertheless, by admixture of chloritic grains and beds of green sand, appear to represent the upper oolite series of England, until, as may be particularly observed in the Salêve, it is difficult not to allow that some characters of the oolitic and cretaceous systems are united in the cap beds of the Jura-kalk. This should be compared with the previous notices of green sand below the Portland oolite, and remembered in discussing the "neocomian" system. The fucoid grits along the line of the Eastern Alps clearly belong to the green sand. The relations of the hippurite limestone, which is at the top of the Alpine kalkstein, show that the causes which in England and the north of France have occasioned *such decided* differences in the oolitic series, and established so many groups, did not obtain in these parts. It is extremely probable that this is merely the difference between

littoral and pelagian deposits. In England, generally, the disturbance of a shore is indicated by the more numerous alternations, beds of clay and sandstone, rolled shells, ripple marks, and land plants; and, where these characters go to extreme, the whole formation appears changed to a coal system. Something like this happens, as before mentioned, at the Porta Westphalica; but the greater part of the oolitic limestone of France, Germany, and the Alps appears to have been deposited in deeper and more quiet waters. Through all these countries the *proportion* of limestone to the more mechanical deposits is much greater than the average of the English series, the marks of disturbance are mostly wanting, the lines of division are obliterated, and the products of the land infrequent. Perhaps we may in this way account for the smaller number of organic remains belonging to the Alpine limestones; for if these were eminently pelagian, they should probably contain fewer marine exuviæ; since we have good reason to believe that the deepest parts of the sea, where light can hardly penetrate, and all is dull repose, are almost devoid of organic life. As the borders of a desert are rich in every vegetable hue, and resonant with all the voices of animals, so are the borders of the sea prolific of existence, but the sahara and the ocean are equally dead at their centre.

The oolitic texture seems to lose itself in the same manner toward the Alps, amongst which it can be seldom seen; and in general the paucity of organic remains is greatest in the most compact or most crystalline of the varieties of these limestones. The Jura, through its whole range in Wurtemberg and Bavaria, uniformly shows upon the lias a cap of rocks associated with sand, and often passing upwards into ferruginous oolite, and the same thing happens above the lias of Hanover and Westphalia.

Solenhofen Beds.—In the centre of the German Jura, at Solenhofen and Eichstadt, occur beds of white fissile limestone, now universally employed in lithography, which abound in organic remains, and have been long supposed to be much related to the Stonesfield slates. This relation is, perhaps, not supported by their geological position; for this is certainly above not only the inferior oolite previously described, but also above a considerable thickness of Jurakalk and a variable mass of dolomite. M. Von Dechen appears to think these beds of an anomalous character, as indeed their organic remains testify. The whole of this slaty group is seen to thin out near the mouth of the Altmühl between masses of dolomite, being entirely surmounted by green sand and cretaceous deposits. (Murchison, *Geol. Proceedings.*) The author just quoted inclined to the opinion that the higher members of the oolitic groups of England had not been satisfactorily defined in any part of central Germany.

Disturbances of the Oolitic System.

The parallelism of beds over large regions, the repetitions of similar rocks at frequent intervals, and the gradual change of the species of organic remains through the whole series, appear to indicate that the long period when the oolitic system was deposited was one in which the ordinary operations of nature were uninterrupted by paroxysms of igneous violence. On viewing the whole series of these strata, and considering the manner in which their outcrops follow one another, it appears that only a very few instances can be pointed out where any beds of the oolitic system are really unconformed to others of the same system below them. Apparent exceptions to this law are indeed presented by every detailed geological map, particularly in the case of the coralline oolite, but this rock appears to have been an irregular and limited deposit. It is, perhaps, hardly enough to justify the term unconformity, to show that some of the upper beds of this system have probably been removed by wasting effects of water before the deposit of the incumbent clay, as at Heddington. One case, however, may be mentioned, at Cave, in Yorkshire, where, amidst the more striking phenomena of unconformity between the oolitic system and the chalk, there appears reason to believe that the deficiency in cornbrash and forest marble systems may be ascribed to a local unconformity of the stratification of the Kelloway rock. Other instances will no doubt be discovered, but they will probably be found equally unimportant.

The case, however, is entirely different, when we transport ourselves to the period immediately following the deposit of the oolites. Through a large part of England the line of the outcrop of the chalk, green sand, &c., follows pretty exactly the range of the oolitic system; and of course we must infer that for all those districts the bed and boundary of the sea were not materially changed, except by gradual purely vertical movement of the earth's crust in the interval between the two systems of strata. But at either extremity of the range the plane of the cretaceous system is carried over the edges of the oolites from the upper to the lower part of the system, so that at Bishop Wilton, in Yorkshire, it rests within 25 feet of the top of the red marl.

In Dorsetshire, the chalk and green sand, by over-extension, rest on all the members of the oolite in succession, and at length, in Haldon, actually touch the red marl.

Murchison, from his interesting observations on the Ord of Caithness, inferred that this granitic mass had been upheaved in a *solid form*, and thus that the contiguous or neighbouring oolitic strata

were broken up. The brecciated character so frequent in these limestones is referred to a subsequent recomposition of the fragmented parts. Without dwelling on other cases in the British dominions, we may fairly infer from this important observation, coupled with the former cases, that there was an extensive disturbance and angular movement in the interior of the earth beneath the sea in which the oolites had been deposited. Considerable faults, ranging E.S.E. and N.N.W., accompany the elevation of the oolites in Yorkshire.

On the continent very extensive disturbances, happening at the same era, show that this was indeed a period when the convulsive energies of the subterranean regions were strongly and extensively exerted.

To this period M. Elie de Beaumont refers a very extensive line of dislocations, connected with the elevation of Mont Pilat near Lyons, the Côte d'Or, and the Erzgebirge. It is observed that all these axes of elevation range north-eastward and south-westward, and in the regions intermediate between these, marking ridges and lines of undulated stratification may be traced in the same north-eastern and south-western direction, particularly on the broad belt of the Jura.

Without insisting upon the exact parallelism ascribed by M. de Beaumont to these lines of disturbance, we are warranted in admitting that to the convulsions at this period the long range of oolites connected with the ridges of the Jura both in France and Germany, and with the line of the Erzgebirge, owe, if not their actual height above the sea, some of their peculiar physical features. The cretaceous system in the vicinity of these lines of disturbance appears to be unaffected by them, except by the new outlines which were then given to the embosoming ocean within which at a later period the chalk, green sand, &c., were deposited.

The oolites which pass north-westward from Lorraine are probably continuous under the whole of the chalky plains of Picardy, but their superficial outcrop is extinguished by the over-extension of the chalk to contact with the slates of the Ardennes, nor is it renewed on the northern side of those mountains. Yet this case may not happen through any unconformity, but be a consequence of the irregular bed of the ancient sea. Thus, the red sandstone may be covered and concealed by the oolite, and the latter may be hidden below the chalk, and yet there may be no unconformity. This view is supported by the successive coming out in proceeding to the south-east from Avesnes, first of the oolite, then of the keuper, muschelkalk, and red sandstone, from their abutments against the older strata.

ORGANIC REMAINS—MIDDLE MESOZOIC SYSTEM.

[The genera supposed to be confined to Mesozoic strata are in small capitals. Foraminifera and Insecta are excepted from this rule.]

PLANTS.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
ALGÆ.						
HALYMENITES,	2	...	2	...	...	...
FILICINÆ.						
ACROSTICHITES,	1	...	1	...	...	...
Alethopteris,	1	...	...	...	...	1
BAIERA,	1	...	1	...	...	...
CTENIS,	1	...	1	...	...	...
Cyclopteris,	3	...	3	...	...	...
Dictyophyllum,	1	...	1	...	...	...
Hymenophyllites,	2	...	2	...	...	...
LONCHOPTERIS,	2	...	1	...	...	1
OTOPTERIS,	3	1	2	...	...	...
PACHYPTERIS,	2	...	2	...	...	...
Pecopteris,	14	...	14	...	...	...
PHLEBOPTERIS,	2	...	2	...	...	...
POLYPODITES,	2	...	2	...	...	...
POLYSTICHITES,	1	...	1	...	...	...
SAGENOPTERIS,	2	...	2	...	...	...
SCHIZOPTERIS,	1	...	1	...	...	...
Sphenopteris,	12	...	8	...	...	4
TÆNIOPTERIS,	5	...	5	...	...	...
EQUISETACEÆ.						
Equisetites,	5	1	2	...	...	2
LYCOPODIACEÆ.						
Lycopodites,	1	...	1	...	...	...
MONOCOTYLEDONEÆ.						
Endogenites,	1	...	...	...	...	1
Lilia,	1	...	1	...	...	...
CONIFERÆ.						
ARAUCARITES,	1	1	...	...	...	...
BRACHYPHYLLUM,	1	...	1	...	...	...
CRYPTOMERITES,	1	...	1	...	...	...
Cupressus,	1	1	...	...	...	...
DAMMARITES,	1	...	...	...	...	1
Peuce,	3	2	1	...	...	...
Pinites,	1	...	1	...	...	...
TAXITES,	1	...	1	...	...	...
THUYTES,	5	...	4	...	...	1

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Walchia,	1	...	1	...	...	...
(Wood),	...	...	...	...	...	...
CYCADEÆ.						
BUCKLANDIA,	1	...	1	...	...	...
CLATHRARIA,	1	...	...	...	...	1
CYCADEOIDEA,	3	1	...	...	...	2
PALÆOZAMIA,	9	2	7	...	...	...
PODOCARYA,	1	...	1	...	...	...
PTEROPHYLLUM,	5	...	4	...	...	1
ZAMIOSTROBUS,	3	...	...	...	...	3
ZAMITES,	3	...	3	...	...	...
(c) Carpolithus,	7	...	4	2	...	2
(c) Strobilites,	1	1	...	...	...	...
CHARACEÆ.						
Chara,	2	...	...	...	...	2
TYMPANOPHORA,	2	...	2	...	...	...
SPHÆROCOCCITES,	2	1	1	...	...	...
SPHÆREDA,	1	...	1	...	...	...
BENSONIA,	1	...	1	...	...	...
STRICKLANDIA,	1	...	1	...	...	...
Calamites ?	1	...	1	...	...	...
NAIADITES,	4	2	2	...	...	...
SALICITES,	1	...	1	...	...	...
SOLENITES,	2	...	2	...	...	...
AMORPHOZOA.						
MANON,	1	...	...	1	...	...
Scyphia,	1	...	...	1	...	...
Spongia,	5	...	4	1	...	...
TALPINA,	1	...	1	...	...	...
FORAMINIFERA.						
Bulimina,	...	...	...	1	...	...
Cristellaria,	?	1	...	1	...	...
Flabellaria,	?	1	...	...	...	...
Frondicularia,	?	1	...	...	...	...
Gaudryina,	?	1	...	...	...	...
Lituola,	2	1	...	...	...	...
Marginulina,	...	1	...	...	...	...
Nodosaria,	?	1	...	...	...	...
Polymorphina,	...	1	1	..	...	...
Rotalina,	...	...	...	1	...	...
Spirolina,	...	...	1	1	...	...
Vulvulina,	...	1	...	...	...	...
Webbina,	...	1	...	...	...	...

ZOOPHYTA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
ZOANTHARIA.						
ANABACIA,	2	...	2	...	...	...
AXOSMILIA,	1	...	1	...	...	...

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Calamophyllia,	1	...	...	1	...	...
Cladophyllia,	2	...	2	...	...	...
Clausastræa,	1	...	1	...	...	...
Comoseris,	2	...	1	1	...	...
Convexastræa,	1	...	1	...	...	...
Cyathophora,	2	...	2	...	...	...
Discocyathus,	1	...	1	...	...	...
Eunomia,	1	...	1	...	...	...
Goniocora,	1	...	...	1	...	...
Isastræa,	12	...	8	3	1	...
Latomeandra,	2	...	2	...	...	...
Microsolena,	3	...	3	...	...	...
Millepora,	1	...	1	...	...	...
Montlivaltia,	12	...	11	1	...	...
Prionastræa,	1	...	1	...	...	...
Protoseris,	1	...	...	1	...	...
Rhabdophyllia,	1	...	...	1	...	...
Stylina,	5	...	3	2	...	...
Thamnastræa,	15	...	12	3	...	...
Thecosmilia,	2	...	1	1	...	...
Trochocyathus,	3	2	1	...	...	...
Zaphrentis,	1	...	1	...	...	...

ECHINODERMATA.

ECHINOIDEA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Acrosalenia,	8	...	7	1	...	...
Cidaris,	12	...	6	3	3	...
Diadema,	8	2	4	3	...	...
Disaster,	4	...	3	1	...	...
Echinopsis,	2	...	2	...	...	...
Echinus,	6	...	5	2	...	...
Goniopygus,	1	...	1	...	...	...
Hemicidaris,	8	...	6	2	...	1
Holectypus,	2	...	2	...	...	...
Hyboclypus,	4	...	3	1	...	...
Nucleolites,	12	...	10	5	...	...
Pygaster,	3	...	2	1	...	...
Pygurus,	4	...	2	3	...	...

ASTEROIDEA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Astropecten,	6	3	2	1	...	...
Luidia,	1	1	...	...	...	...
Solaster,	1	...	1	...	...	...
Tropidaster,	1	1	...	...	...	...
Uraster,	1	1	...	...	...	...

OPHIUROIDEA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Amphiura,	2	...	...	2	...	...
Aspidura,	1	1	...	...	...	...
Ophioderma,	3	3	...	...	...	...
Ophiura,	1	1	...	...	...	...

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
CRINOIDEA.						
APIOCRINUS, . .	4	...	4	...	...	...
BOURGUETICRINUS? .	1	...	1	...	...	...
EXTRACRINUS, . .	2	2	...	...	...	...
MILLERICRINUS, .	2	...	1	...	...	...
Pentacrinus, . .	9	5	5	1	...	...
ANNELIDA.						
Serpula, . . .	21	2	16	6	...	...
Vermicularia, . .	3	...	2	2	...	...
Vermilia, . . .	2	...	1	1	...	...
CIRRIPEDA.						
Pollicipes, . . .	3	...	1	2	...	...
CRUSTACEA.						
ARCHÆONISCUS, .	2	...	...	...	...	2
Astacus, . . .	3	1	...	2	...	...
COLEIA, . . .	2	2	...	...	...	...
CYPRIDEA, . .	5	...	...	...	...	5
Cypris, . . .	1	1	...	...	...	...
ESTHERIA, . . .	4	1	1	...	...	2
GLYPHIA, . . .	3	1	1	2	...	...
MECOCHEIRUS, . .	1	...	...	1	...	...

INSECTA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
COLEOPTERA.						
Berosus, . . .	1	1	...	...	...	...
Carabus, . . .	2	...	...	...	...	2
Cerylon, . . .	1	...	...	...	...	1
Coccinella, . . .	1	...	1	...	...	...
Colymbetes, . .	1	...	...	...	...	1
Curculionides, . .	1	...	1	...	...	...
Cyphon, . . .	1	...	...	...	...	1
Elaterium, . . .	4	1	...	...	...	3
Gyrinus, . . .	1	1	...	...	...	...
Helophorus, . .	1	...	...	..	...	1
Laccophilus, . .	1	1	...	...	...	...
Limnius, . . .	1	...	...	...	...	1
Melolontha, . .	1	1	...	...	...	...
Prionus, . . .	1	...	1	...	...	...
Rhyncophora, . .	1	...	...	...	...	1
Curculium, . .	1	...	...	...	...	1
Buprestium, . .	7	...	...	...	...	7
Blapsium, . . .	1	...	1	...	...	...
Harpalidium, . .	2	...	...	...	...	2
Tentyridium, . .	1	...	...	..	...	1
Agrillium, . . .	4	...	...	...	...	4
Helopidium, . .	2	...	...	...	...	2
Telephorium, . .	1	...	...	...	...	4
Ctenicerium, . .	2	...	...	...	...	2

NEUROPTERA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Æshnidium, . .	4	2	...	...	...	2
Agrionidium, . .	2	1	...	...	...	1
Chauliodes, . . .	1	1	...	...	...	...
Corydalis, . . .	1	...	...	...	...	1
Ephemera, . . .	1	1	...	...	...	...
Hemerobioides, . .	2	1	1	...	...	...
Leptocera, . . .	1	...	...	...	...	1
Libellulium, . .	3	2	...	...	...	2
Lindenia, . . .	1	...	...	...	...	1
Orthophlebia, . .	1	1	...	...	...	...
Phryganea, . .	1	...	...	...	...	1
Termitidium, . .	2	...	...	...	...	2
Panorpidium, . .	1	...	...	...	...	1
Phryganidium, . .	1	...	...	..	...	1
Raphidium, . .	1	...	...	...	...	1
Sialium, . . .	1	...	...	...	...	1

DIPTERA.

Asilum, . . .	1	1	...	...	...	...
Chironomum, . .	2	...	...	...	...	2
Corethrium, . .	1	...	...	...	...	2
Simulidium, . .	2	...	...	...	...	2
Tanypium, . .	1	...	...	...	...	1
Cecidomidium, . .	1	...	...	...	...	1
Culicium, . . .	1	...	...	...	...	1
Empidium, . .	1	...	...	...	...	1
Macrocercium, . .	1	...	...	...	...	1
Macropezium, . .	1	...	...	...	...	1
Platyura, . . .	1	...	...	...	...	1
Rhyphus, . . .	1	...	...	...	...	1
Sciophila, . . .	1	...	...	...	...	1

HOMOPTERA.

Aphidium, . .	2	...	...	...	...	2
Cercopidium, . .	5	...	...	...	...	5
Asiracum, . .	1	...	...	...	...	1
Cicadellium, . .	3	1	...	...	...	2
Cixium, . . .	1	...	...	...	...	1
Cimilidium, . .	2	1	...	...	...	1
Delphax, . . .	1	...	...	...	...	1
Nepadeum, . .	1	...	...	...	...	1
Kleidocerys, . .	1	...	...	...	...	1
Ricania, . . .	2	1	...	...	...	1

ORTHOPTERA.

Blattidium, . .	6	1	...	...	...	5
Gryllidium, . .	2	1	...	...	...	1
Achitidium, . .	1	...	...	...	...	1

HYMENOPTERA.

Formicium, . .	1	...	...	...	...	1
Myrmecium, . .	1	...	...	...	...	1

LEPIDOPTERA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Cyllonium,	2	...	...	...	...	2

BRYOZOA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Alecto,	1	...	1	...	...	...
Aspendesia,	1	...	1	...	...	...
Ceriopora,	3	...	3	...	...	...
Chrysaora,	3	...	3	...	...	...
Cricopora,	3	...	3	...	...	...
Diastopora,	4	...	4	1	...	...
Heteropora,	3	...	3	1	...	...
Hippothoa,	1	...	1	...	...	...
Idmonea,	1	...	1	...	...	...
Intricaria,	1	...	1	...	...	...
Terebellaria,	2	...	1	1	...	...
Theonoa,	1	...	1	...	...	...

BRACHIOPODA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Crania,	2	1	1	...	...	...
Discina,	6	2	1	2	1	...
Leptæna,	5	5	..	...	...	...
Lingula,	2	1	1	1	1	...
Rhynconella,	30	9	19	2	1	...
Spirifera,	5	5	...	...	...	...
Terebratella ?	1	...	1	...	...	...
Terebratula,	42	12	28	4	...	...
Thecidium,	5	3	2	...	...	...

MONOMYARIA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Anomia,	2	...	1	1	...	...
Avicula,	18	5	8	5	...	...
Crenatula,	3	1	1	1	...	...
Exogyra,	4	...	1	2	3	...
Gervillia,	16	2	13	2	1	...
Gryphæa,	14	5	3	5	1	...
Hinnites,	3	...	3	...	...	...
Inoceramus,	5	1	4	...	...	...
Lima,	25	6	16	7	1	...
Limea,	1	...	1	...	...	...
Ostrea,	21	...	11	7	5	...
Pecten,	34	3	24	9	4	...
Plcunopsis,	6	...	6	...	...	...
Pinna,	7	1	4	2	1	...
Plicatula,	4	2	2	...	...	...
Pteroperna,	4	...	4	...	...	...
Trichites,	2	...	1	1	...	...

DIMYARIA.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Anatina,	3	...	1	2	...	[illegible]
Arca,	17	3	13	3	[illegible]	[illegible]

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Astarte, . . .	23	...	14	6	4	...
Cardinia, . . .	11	9	3	1	...	...
Cardium, . . .	20	1	15	1	4	...
CEROMYA, . . .	5	...	5	...	...	...
Corbis, . . .	5	1	2	2	...	...
Corbula, . . .	3	...	2	1	...	...
Cucullæa, . . .	17	...	13	6	...	...
Cypricardia, . .	4	...	4	...	...	...
Cyprina, . . .	1	...	1	...	...	...
Cyrena, . . .	12	...	4	...	...	8
Cytherea, . . .	1	...	1	...	...	...
GONIOMYA, . .	4	1	3	2	...	...
GRESSLYA, . .	6	1	5	...	...	...
HIPPOPODIUM, . .	1	1	...	...	...	...
Isocardia, . . .	9	...	7	3	...	...
Leda, ...	5	2	2	1	...	...
Limopsis, . . .	1	...	1	...	...	...
Lithodomus, . .	4	...	3	2	...	...
Lucina, . . .	6	...	4	2	1	...
Lutraria, . . .	1	...	1	...	...	...
Mactra, . . .	1	...	1	...	...	...
Modiola, . . .	25	6	15	4	1	...
Mya, ...	1	...	1	...	...	...
Myacites, . . .	21	2	16	3	1	...
MYOCONCHA, . .	3	...	1	...	...	...
Mytilus, . . .	4	...	2	...	1	1
Neæra, . . .	1	...	1	...	...	...
Nucula, . . .	7	1	5	2	...	...
OPIS, ...	6	...	5	1	...	...
PACHYRISMA, . .	1	...	1	...	...	...
Pectunculus? . .	1	...	1	...	...	...
Pholadomya, . .	24	5	14	4	1	...
Pholas, . . .	2	...	...	1	1	...
Potamomya, . .	2	...	2	...	...	...
Psammobia, . .	2	...	1	...	...	1
Pullastra, . . .	2	...	2	...	...	...
Sanguinolaria, . .	2	1	1	...	...	...
SPHÆRA, . . .	1	...	1	...	...	...
TANCREDIA, . .	6	...	6	1	...	...
Tellina, . . .	1	...	...	1	...	...
Thracia, . . .	2	...	1	1	...	...
Trigonia, . . .	30	1	25	2	4	...
UNICARDIUM, . .	5	1	4	...	...	...
Unio, ...	12	...	2	...	...	10

No Pteropods known.

GASTEROPODA.

Actæon, . . .	5	...	3	1	...	1
ACTÆONINA, . .	7	...	7	...	...	...
ALARIA, . . .	15	...	13	3	...	...
Brachytrema, . .	2	...	2	...	...	...
Buccinum? . .	1	...	...	...	1	...

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Bulla,	4	...	2	1	...	1
Ceritella,	9	...	9	...	...	...
Cerithium,	15	...	11	1	2	1
Chemnitzia,	15	...	12	2	1	...
Cirrus,	3	...	2	1	...	...
Cylindrites,	11	...	11	...	...	...
Delphinula,	6	...	6	...	...	...
DESLONGCHAMPIA,	1	...	1	...	...	...
Emarginula,	3	...	3	...	...	...
Eulima,	4	...	4	..	...	...
Euomphalus?	1	...	1	...	...	...
Fissurella,	1	...	1	...	...	...
Fusus,	3	...	3	...	...	...
Hydrobia,	1	...	1	...	...	...
Littorina,	2	...	2	1	...	...
Monodonta,	7	...	7	...	...	...
Murex,	1	...	...	1	...	...
Natica,	11	...	8	3	1	...
NERINÆA,	17	...	14	3	...	...
Nerita,	5	...	5	...	...	...
Neritina,	2	...	1	...	...	1
NERITOMA,	1	...	...	...	1	...
NERITOPSIS,	3	...	3	...	...	...
Paludina,	4	...	...	...	...	4
Patella,	14	...	13	...	1	...
Phasianella,	11	...	11	1	...	...
Physa,	1	...	...	...	...	*
PILEOLUS,	2	...	2	...	...	...
Planorbis,	1	...	...	...	...	*
Pleurotomaria,	24	3	16	4	2	...
Pterocera,	3	...	3	...	...	...
Purpurina,	3	...	3	1	...	...
RIMULA,	3	...	3	...	...	...
Rissoina,	6	...	6	...	...	...
Solarium,	4	...	4	...	...	...
SPINIGERA,	2	...	1	1	...	...
Stomatia,	1	...	1	...	...	...
TROCHOTOMA,	9	...	9	...	...	...
Trochus,	23	1	20	2	...	...
Turbo,	13	1	10	2	...	...
Turritella,	4	...	1	2	1	...

CEPHALOPODA.

ACANTHOTEUTHIS,	1	...	...	1	...	...
AMMONITES,	209	123	34	45	7	...
ANCYLOCERAS,	2	...	1	1	...	...
BELEMNITES,	27	13	6	7	...	...
Nautilus,	16	8	8	1	...	...

PISCES.

PLACOID FISHES.

Hybodontidæ.						
HYBODUS,	24	10	9	1	3	2

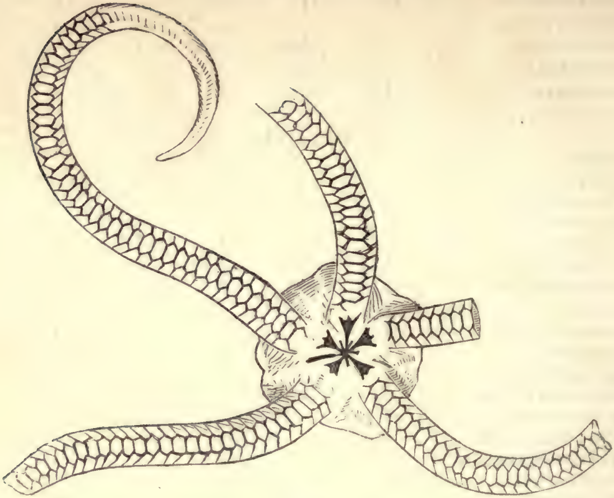
	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Sphenonchus,	3	1	1	...	...	1
Cestraciontidæ.						
ACRODUS,	8	5	2	...	...	1
ASTERACANTHUS,	8	1	3	...	3	1
CERATODUS,	1	...	1	...	...	...
Leptacanthus,	3	1	2	...	...	...
Nemacanthus,	1	...	1	...	...	...
STROPHODUS,	6	...	4	1	1	...
Lamnidæ.						
OXYRHINA,	1	...	...	...	...	1
THYELLINA,	1	1	...	...	...	...
Raiidæ.						
ARTHROPTERUS,	1	1	...	...	...	...
CYCLARTHRUS,	1	1	...	...	...	...
MYRIACANTHUS,	3	3	...	...	...	...
SQUALORAIA,	1	1	...	...	...	...
Edaphodontidæ.						
GANODUS,	10	...	10	...	...	...
ISCHYODUS,	3	1	...	...	2	...

GANOID FISHES.

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
Sauroidæ.						
ASPIDORHYNCHUS,	3	1	...	1	...	1
BELENOSTOMUS,	3	2	1	...	...	...
CATURUS,	3	1	1	...	1	...
CENTROLEPIS,	1	1	...	...	...	...
CONODUS,	1	1	...	...	...	...
COSMOLEPIS,	1	1	...	...	...	...
EUGNATHUS,	13	13	...	...	...	...
LEPTOLEPIS,	9	5	...	2	...	2
MACROSEMIUS,	1	...	1	...	...	...
OXYGNATHUS,	1	1	...	...	...	...
OXYGONUS,	1	...	...	...	...	1
PACHYCORMUS,	10	10	...	...	...	...
PTYCHOLEPIS,	3	3	...	...	...	...
SAUROPSIS,	1	...	1	...	...	...
THRISSONOTUS,	1	1	...	...	...	...
Pycnodontidæ.						
GYRODUS,	5	...	2	2	...	1
GYRONCHUS,	1	...	1	...	...	...
MICRODON,	1	...	...	...	...	1
PYCNODUS,	14	1	12	...	...	1
SCAPHODUS,	1	...	1	...	...	...
SPHÆRODUS,	1	...	...	...	1	...
TETRAGONOLEPIS,	1	1	...	...	...	...
Lepidoideæ.						
ÆCHMODUS,	12	11	...	...	...	1
AMBLYURUS,	1	1	...	...	...	...
DAPEDIUS,	8	8	...	...	...	...
HISTIONOTUS,	1	...	...	...	1	...
LEPIDOTUS,	12	6	2	...	1	2
Nothosomus,	1	1	...	...	...	...

	No. of Species.	Lias.	L. Oolite.	M. Oolite.	U. Oolite.	Wealden.
OPHIOPSIS, . .	3	...	...	...	...	3
PHOLIDOPHORUS, .	15	11	2	...	...	2
PLEUROPHOLIS, . .	1	...	...	...	...	1
SEMIONOTUS, . .	1	1	...	...	...	...
Coilacanthidæ.						
CTENOLEPIS, . .	1	...	1	...	...	...
REPTILIA.						
Dinosauria.						
CARDIODON, . .	1	...	1	...	...	...
HYLÆOSAURUS, . .	1	...	...	...	...	1
IGUANODON, . .	1	...	...	...	...	1
MEGALOSAURUS, .	1	...	1	1	...	1
REGNOSAURUS, . .	1	...	...	...	...	1
STENEOSAURUS, . .	1	...	1	...	1	...
Crocodilia.						
CETIOSAURUS, . .	4	...	2	...	1	2
Crocodilus, . . .	1	...	...	...	...	1
GONIOPHOLIS, . .	1	...	...	...	...	1
MACRORHYNCHUS, .	1	...	...	...	...	1
PELOROSAURUS, . .	2	...	...	...	...	2
POIKILOPLEURON, .	1	...	...	...	...	1
STREPTOSPONDYLUS, .	4	1	2	...	...	1
SUCHOSAURUS, . .	1	...	...	...	...	1
TELEOSAURUS, . .	3	1	1	...	1	...
Lacertilia.						
Lacerta, . . .	1	...	1	...	...	...
MACELLODUS, . .	1	...	...	...	...	1
NOTHETES, . .	1	...	...	...	...	1
Enaliosauria.						
ICHTHYOSAURUS, .	10	9	...	...	1	...
PLESIOSAURUS, . .	12	9	...	...	3	...
PLIOSAURUS, . .	3	...	...	...	3	...
Chelonida.						
Chelone, . . .	3	...	...	...	1	2
Platemys, . . .	3	...	...	...	...	3
PLEUROSTERNON, .	4	...	...	...	...	4
Testudo, . . .	1	...	1	...	...	...
TRETOSTERNON, . .	1	...	...	...	...	1
Trionyx, . . .	1	...	1	...	...	...
Pterodactylida.						
PTERODACTYLUS, .	3	1	1	...	...	1
MAMMALIA.						
AMPHITHERIUM, .	2	...	2	...	...	...
PHASCOLOTHERIUM, .	1	...	1	...	...	...
SPALACOTHERIUM, .	1	...	...	...	...	1
STEREOGNATHUS, .	1	...	1	...	...	...
BIRDS.						
PALÆORNIS, . .	1	...	...	...	...	1

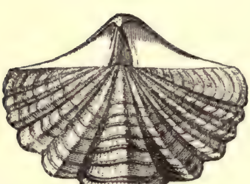
LIAS FOSSILS.



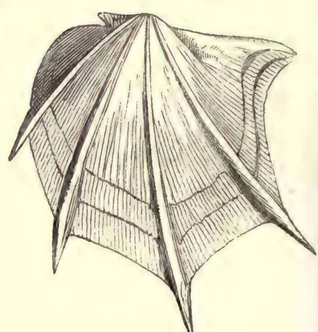
193

194

195

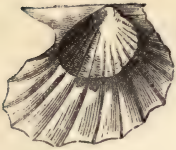


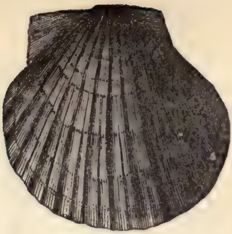
196



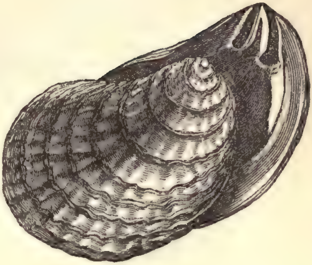
197

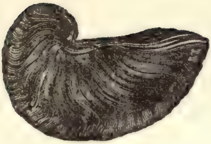
193 Ophiura milleri. 194 Diadema seriale. 195 Rhynconella acuta.
196 Spirifer Walcottii. 197 Avicula cygnipes.

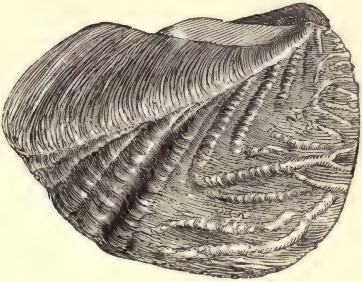

198


199


200

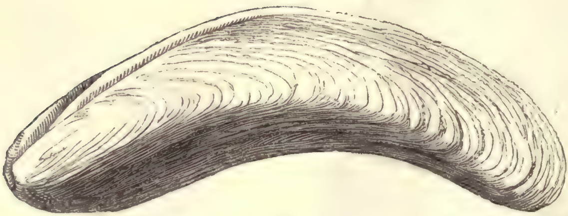

201


202


203

198 Avicula inequivalvis.
199 Pecten lugdunensis.
200 Plagiostoma giganteum.
201 Plicatula spinosa.
202 Gryphea incurva.
203 Trigonia literata.

204



205

206

207

204 Corbula cardioides.
205 Modiola scalprum.

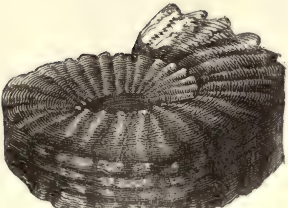
206 Cardium truncatum.
207 Ammonites crassus.

208

209

212

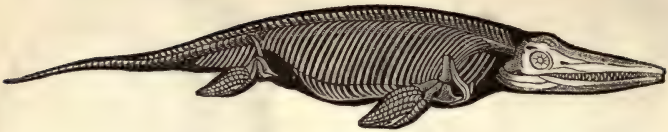
213



210

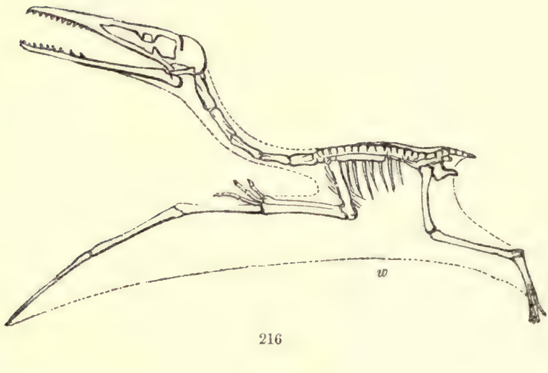
211

208 Ammonites Clevelandicus.
209 Ammonites.
210 Ammonites Bucklandi.
211 Ammonites Walcottii.
212 Belemnites pistiliformis.
213 Ink bag of a cephalopod.



214

215

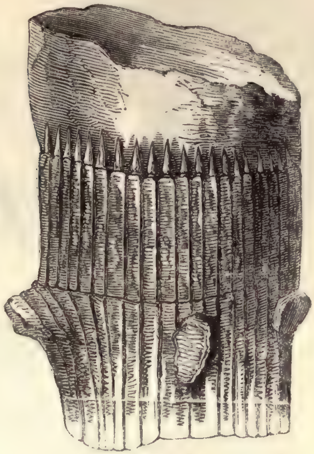


216

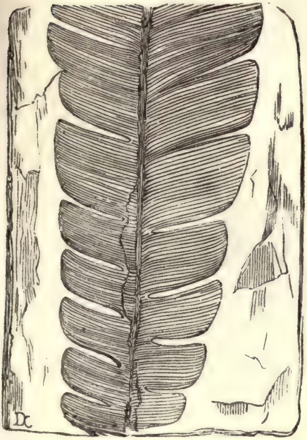
214 Ichthyosaurus communis. 215 Plesiosaurus dolichodeirus.
216 Pterodactylus longirostris (*w*, probable edge of the wing).

LOWER OOLITE FOSSILS.

217



218

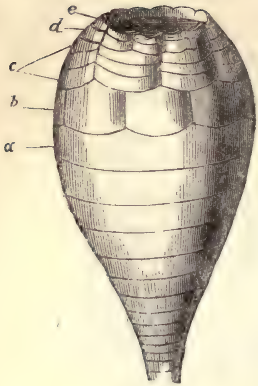


219

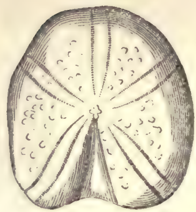
220

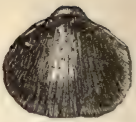
217 Tæniopteris vittata.
218 Equisetum columnare.

219 Pterophyllum comptum.
220 Brachyphyllum mammillare.

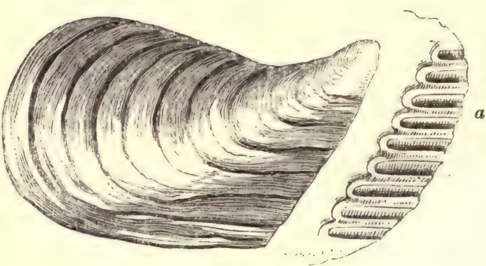


221


222

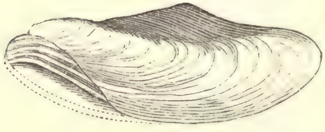

223


224



226

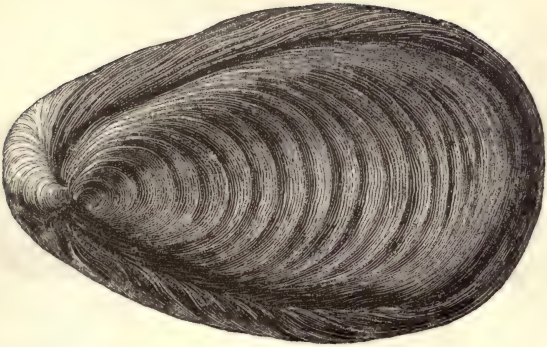

225


227

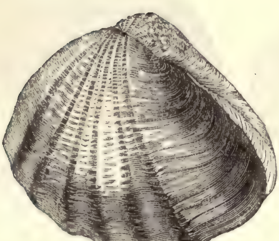
221 Apiocrinus rotundus.
222 Nucleolites clunicularis.
223 Rhyncon. spinosa.
224 Terebratula globosa.
225 Terebratula digona.
226 Perna quadrata (*a*, the hinge).
227 Gervillia lanceolata.

228

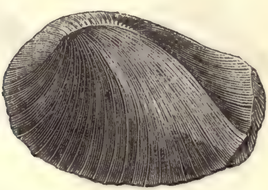
229



230

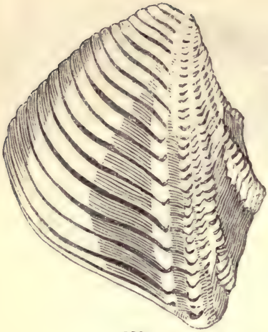


231



232

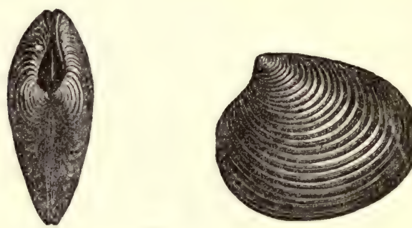
228 Ostrea Marshii.
229 Ostrea Sowerbii.
230 Gryphæa cymbium.
231 Pholadomya Murchisoni.
232 Pholadomya acuticosta.



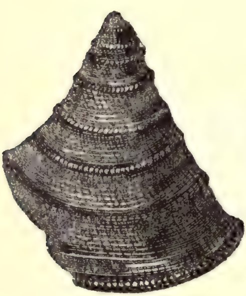
233

234

235



236



237

238

239

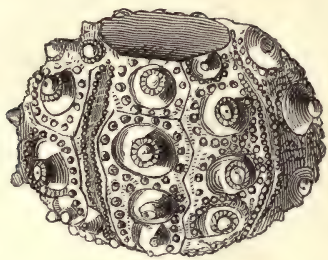
233 Trigonia costata.
234 Isocardia concentrica.
235 Astarte minima.
236 Astarte elegans.
237 Pleurotomaria conoidea.
238 Ammonites Brongniarti.
239 Ammonites striatulus.

240

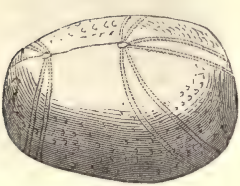
240 Phascolotherium Bucklandi.

MIDDLE OOLITE FOSSILS.

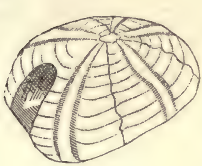
241



242



243

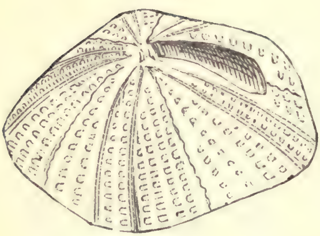


244

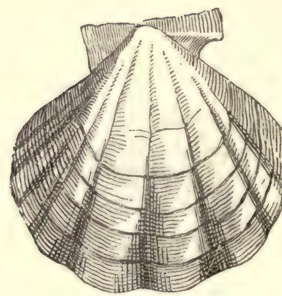
241 Cidaris coronata.
242 Cidaris florigemma.

243 Disaster ovalis.
244 Nucleolites dimidiatus.

246



245



248

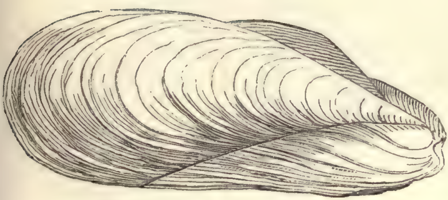
247

249

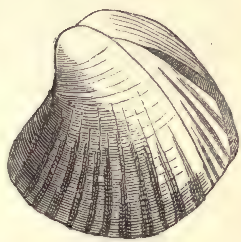
245 Clypeus semisulcatus.
246 Disaster bicordatus.
247 Serpula squamosa.
248 Pecten inæquisulcatus.
249 Gryphæa dilatata.

250

256



251



252

253

254

255

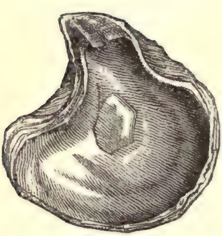
250 Trigonia clavellata.
251 Modiola bisulcata.

252 Isocardia rhomboidalis.
253 Nerinæa Goodhallii.
256 Belemnites sulcatus.

254 Turbo muricatus.
255 Ammonites calloviensis.

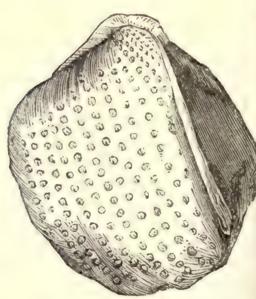
UPPER OOLITE FOSSILS.

257



258

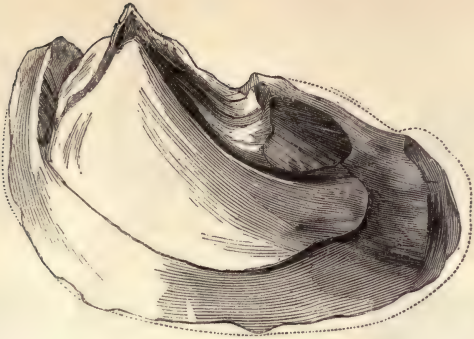
259



260

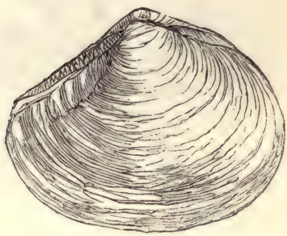
257 Pecten lamellosus.
258 Ostrea deltoidea.

259 Exogyra virgula.
260 Trigonia gibbosa.



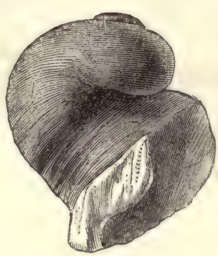
261

262



263

264

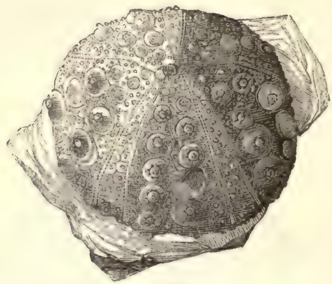


265

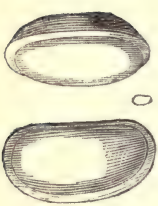
261 Cast of Trigonia.
262 Cardium dissimile (cast).
263 Thracia depressa.
264 Terebra Portlandica (cast).
265 Nerita angulata (cast).

WEALDEN FOSSILS.

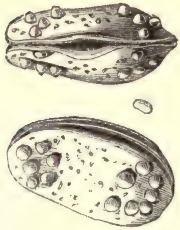
266



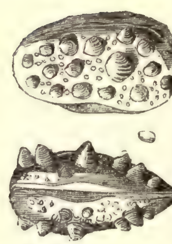
267



268

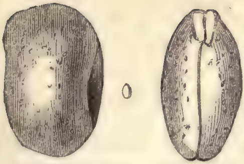


269



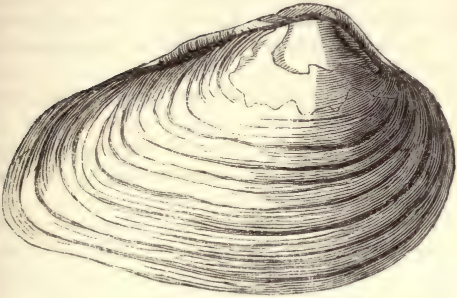
270

266 Mantellia nidiformis.
267 Hemicidaris Purbechensis (middle Purbeck).
268 C. Purbechensis (lower Purbeck).
269 Cypridina fasciculata (middle Purbeck).
270 Cypridina tuberculata (upper Purbeck).

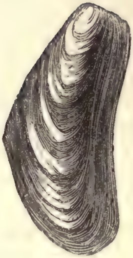


271

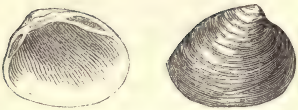
272



273



274



275

276

277

271 Cypridina Valdensis (Wealden).
272 Archæoniscus Brodiæ (middle Purbeck).
273 Uno Valdensis.
274 Modiola Fittoni (Purbeck).
275 Cyrena Media (Wealden).
276 Paludina fluviorum (Wealden).
277 Physa Bristovii (middle Purbeck).

CHAPTER XI.

UPPER MESOZOIC STRATA.

Cretaceous System.

Mineral Character.—That a peculiar type of mineralogical character belongs to each system of formations must have been sufficiently evident through the whole course of our investigation. The gneiss and mica slate system, the Cambrian and Silurian systems, the limestones of the carboniferous system, the coloured marls and magnesian limestones of the Permian and saliferous systems, the oolites, are all resting points for the mind, and amidst a multitude of shades and gradations, strongly impress upon us the distinctive features of the several periods of time at which these so different rocks were in a predominant degree produced.

Mineral characters alone, when rightly used, are in many instances sufficient to determine the geological relations of even distant regions; and when conjoined with the evidence of organic remains, and controlled by careful survey of the strata above and below, they form a secure groundwork for topographical geology.

The cretaceous system is equally definite as any of the others with respect to the distinctness of its prevailing mineral ingredients, and not less characteristically marked by peculiar marine exuviæ. Chalk and green sands are terms understood by all the geologists of northern Europe; and even on the southern side of the Alps their representatives may be recognized.

Surface of Country.—Through England the ranges of chalk hills form a geographical feature even more important than that of the oolites; for though in general not so elevated, they are less interrupted and more extensive, more uniform in composition, and therefore more characteristic in aspect. The chalk hills form the first great ridge which is to be crossed from the eastern side of the island, and nothing can be more remarkable or instructive than such a journey. On approaching these broad hills from the level or gently undulated plains of the eastern counties, or the clay vales of the oolite system, the country changes entirely. The streams run in smoothly sloping valleys, the hills rise with beautiful swells into a long waving outline, seldom broken by a tree, but often capped by an ancient tumulus. Arrived on the summit, we behold a mighty extent of broadly undulated land with abundance of depasturing cattle, but few habitations of men. Plants, eminently characteristic of calcareous soil, force themselves on the attention; flints abound in the fields, chalk

is cut through in the roads, the soil is thin, the herbage short, the surface dry, and we feel ourselves in a new physical region.

This impression is confirmed when we observe more carefully the numerous undulations upon the surface of the "wolds;" for all these may be traced into connection as so many ramifications of greater valleys, which themselves often unite, and pursue a considerable course without enclosing even the smallest rill, or showing even the mark of a watercourse. These *dry valleys* descend from their origin in regular slopes, and are clearly the work of water, operating with great force, and for some time, but in the present system of nature the watery agent has wholly disappeared.

The rains are absorbed as fast as they fall upon this dry surface, and sink to considerable depths in the rock, where they are treasured up in reservoirs to supply the deep wells and the constant springs which issue at lower levels.

In a word, broad, swelling hills, smooth, winding, often dry valleys, and a bare, dry, grassy surface are the general features of the chalky districts. This character of surface belongs, as Dr. Lister remarked long ago, to the chalk wolds of Yorkshire, Lincolnshire, Norfolk, Suffolk, Berks, Wilts, Dorset, Hampshire, Surrey, Kent, and Sussex.

Groups of the System.—The cretaceous system forms conveniently two formations. Supposing the whole to be present in a single section, we should have the following general series:—

Chalk formation.	*f* Upper chalk, with abundance of flints in layers and nodules.
	e Middle part (usually called lower) chalk, with fewer flints.
	d Lower part (usually called chalk marl, or malm.)
Green sand formation.	*c* Upper green sand, malm rock, or firestone.
	b Gault clay.
	a Lower green sand or iron sand.

d and *c* are sometimes undistinguishable. The lower green sand generally forms a distinct ridge, which may even exceed the chalk in height.

The complete system here presented occurs in many parts of Kent, Sussex, and Hampshire; but generally in other parts of England the sections are modified, so as to present only partial assemblages of the beds, sometimes one, sometimes another being deficient; and with respect to the malm rock, great differences are observable. Thus, in Wiltshire, where Smith took the type of this formation, we have the upper green sand remarkably developed; the lower one and the gault are contracted.

f Chalk upper, *e* lower	500 feet.
d Chalk marl	100
c Green, gray, and yellow sand	120
b Gault	50
a Lower green sand	30

Along the line of chalk hills from the valley of the Thames to Lynn, the upper green sand is almost lost in the chalk marl and gault; green grains being mixed with the former, and still more in the upper layers of the latter. In Bedfordshire, the chalk marl produces a bed of siliceous, chalky stone, which may probably be analogous to the firestone of Mesterham in Surrey, which is determined to belong to the upper green sand series. Indeed the sections along this part of the chalk range are very similar to those of Sussex and Kent.

In Lincolnshire we meet with a new feature, a band of red chalk, at the base of the white rock; under this no upper green sand, and generally no gault, but the red chalk rests upon a thick series of greenish and ferruginous sands, with included beds of sandy limestone, full of fossils resembling those of the lower green sand of Kent. This county has been very badly represented in most of our maps.

In Yorkshire the cretaceous system consists of—

Upper chalk.
Lower chalk and traces of chalk and marl.
Red band of chalk.
Gault with green grains passing downwards into Kimmeridge clay, without the intervention of the lower green sand.

From several researches abroad it has been thought that the chalk group of England and France is imperfect in the upper terms, and that the well-known Maestricht beds, and the more recently investigated Gosau beds, appear to soften the transition from the chalk to the true tertiary strata. We shall now briefly trace the history of these several members of the green sand and chalk groups, beginning as usual with the lowest.

We are indebted to Dr. Fitton for a very laborious collection of the natural sections which many parts of England offer, to illustrate this series of strata. He has also tabulated the organic remains, and thus honourably connected his name with the "green sand." *

The Lower Green Sand. (Syn. Iron Sand, Shanklin Sands, &c.)— In Lincolnshire the lower green sand is a considerable mass of yellow, often very irony sand, forming, toward the west, poor heaths upon the Kimmeridge clay, exactly like those about Lynn, Ampthill, and Godstone. It contains a good deal of bad ochre, very similar to that of Shotover Hill, and lines of oxide of iron like that of Ryegate. Beds of gray stone, blue within, flat-bedded, sandy, and full of fossils, lie in it, and afford excellent road materials. These are dug at Tealby, Market Stainton, Ludford, Cawkwell, Bluestone Heath, Stainton in the Hole, &c. It has considerable resemblance to the Kentish rag, and contains exogyra sinuosa, pecten cinctus, plagiostomata, serpulæ, ammonites, alcyoniform bodies, small corals, and many other fossils; but echini and belemnites appear unknown

* Geological Transactions, 2d series, vol. iv., and Geol. Journal for 1847.

in it. From these details it is evident that the stratum has the most decided characters of lower green sand. It is exposed by denudations in the chalk, and also ranges on the west of the wolds for a great length by Rasen, Lessington, Linwood, &c., to Louth. The whole thickness is probably 100 feet. These notices are partly derived from personal observations in 1821, but principally from a special visit to the district in 1833 with two friends, Mr. W. H. Dikes and Mr. J. E. Lee, who have fully explored it. Mr. Lee made an excellent model of it.

As usual in coloured sands, this stratum often contains veins of perfectly white sand. At Lynn this has been found of value for the glass-houses. In Cambridgeshire and through Huntingdonshire, the iron sand forms a narrow course of low hills; but through Bedfordshire and Buckinghamshire it takes a commanding station, forming heathy ridges from Potton to Woburn, and through Buckinghamshire and Oxfordshire, capping Brickhill and Brill Hills, Shotover Hill, Cumnor Hurst, and Faringdon Clump. In Wiltshire, Spy Park, Bowood, Seend Hill, are capped by these beds; but they are supposed to thin out to the south, and to be lost, until in Blackdown they are probably associated with the upper green sand. In the Isle of Purbeck and the Isle of Wight it is an important rock, and, as observed before, encircles the whole of the Wealden formation of Kent and Sussex.

Through the whole of its range from Cambridgeshire into Wiltshire it is a highly ferruginous sand, with spheroidal or merely irregular concretions of oxide of iron, frequently enclosing a coarse brown ochre. At Shotover, the fine yellow ochre forms two irregular beds, separated by a thin parting of clay. Fuller's earth also occurs in it in layers in Bedfordshire, especially at Woburn. Grains of green sand abound in some layers of these beds in Bedfordshire and Buckinghamshire, and constitute it a real green sand. Chert layers also are formed in it, and many of the beds assume the aspect of coarse conglomerate, used by the ancient Britons for the making of quern stones or carstones, whence Smith gave this name as a synonym of the iron sand. Fossil wood is frequent in these beds. In Bedfordshire its thickness may be stated at 100 feet; in Wiltshire Lonsdale finds it 30.

In the Isle of Purbeck, the iron sand consists of many beds of quartzose conglomerate, and of coarse and fine grained sandstones, containing beds of wood coal. In the Isle of Wight, dark red ferruginous sandstones in the upper part, and alternations of red and yellow ferruginous sands and clays in the lower part, form the substance of all the southern half of the island, and contribute much to the beauty of the scenery of the Undercliff.

In its long course around the Wealds of Kent and Sussex, the

lower green sand presents, with the general characters noticed above, some local peculiarities of interest. In Leith Hill, its extended plateau makes a commanding feature, and shows a great thickness of brown sands, with abundance of chert, with confluent grains passing into chalcedony, and some alcyonites like those of the Isle of Wight.

The importance of the lower green sand as a geographical feature diminishes as it proceeds round the south side of the Weald, but the northern range is generally elevated and remarkably continuous by Ryegate, Nutfield, and Maidstone to Hythe and Folkstone. At Ryegate it is almost exactly like the ferruginous rock of Woburn; at Nutfield it produces beds of Fuller's earth; from Maidstone to Hythe and Folkstone the sands are in general remarkably, and even excessively rich in green grains and nodules, and contain beds of whitish limestone, sometimes chalky and often cherty, with green grains, considerably rich in ammonites, trochi, cardia, pectens, lutrariæ, exogyræ, echinites, and other fossils. These beds may be generally called Kentish rag. Some of them are of a dark gray colour, very hard, full of green grains, and rich in many fossils, some of which are usually found in the upper green sand. The cherty beds of Leith Hill and Haslemere are probably the representatives of these calcareo-siliceous layers.

Some of the beds of lower green sand about Folkstone are excessively coarse in the grain, and absolutely crammed with green grains and nodules. The large species of exogyra is very frequent, and appears characteristic. The blue marl or gault rests immediately on the sandy beds.

Dr. Fitton presents the following detailed sections of the lower green sand at Atherfield, Isle of Wight, where, and between this place and Blackgang, the whole series is seen from the Wealden formation below to the gault above.* The thickness here is 808 feet; at Hythe, near Folkstone, according to Mr. Simms, 406½ feet.

		Ft.	In.
49 to 55	Various clays and sands	118	4
46 to 48	Upper clays and sand rock	118	0
45	Ferruginous bands of Blackgang above	20	6
41 to 44	Sands of Walpen, under cliff	97	0
40	Foliated clay and sand	25	0
38, 39	Cliff-end sands	19	3
36, 37	Second Gryphæa beds	16	0
35	Walpen and Ladder sands	42	0
26 to 34	Upper Crioceras group	46	2
24, 25	Walpen clay and sands	57	0
17 to 23	Lower Crioceras group	16	3
14 to 16	Scaphites group	50	4
11 to 13	Lower Gryphæa beds	32	0
4 to 10	The 'Crackers'	85	0
3	Atherfield clay	60	0
1, 2	Perna beds	5	3

* Geological Journal, 1847.

In the 55 groups thus placed the distribution of 155 species of fossils is carefully traced. The general result is as under:—

No. of groups.	No. of fossils.	No. of groups.	No. of fossils.	No. of groups.	No. of fossils.
55	1	34 *b*	2	16	7
54 to 50	0	33	13	15	7
49	1	32	3	14	4
48	0	31	2	13	19
47	1	30	0	12	3
46	0	29	3	11	4
45 *b*	34	28	0	10	12
a	12	27	3	9	27
44	4	26	2	8	19
43	0	25	11	7	27
42	8	24	5	6	5
41	0	23	2		2
40	0	22	0		10
39	0	21	2	5	1
38	5	20	11		43
37	6	19	6		13
36	9	18	8	4	32
35 *b*	4	17	10	3	23
a	14			2	53
				1	46

The relative abundance of life in the lower part of this great series of sands and clays is remarkable. If we range the sixteen larger groups in succession, and count the species in the several beds (including repetitions), we have the following result:—

Larger groups.	No. of species including repetitions.	Repetitions in each group.	No. of distinct fossil species in each large group.
16	2		2
15	1	1	0
14	46	11	35
13	12	8	4
12	0	0	0
11	5	4	1
10	15	9	6
9	18	14	4
8	28	23	5
7	16	11	5
6	39	24	13
5	18	16	2
4	26	16	10
3	191	115	76
2	23	12	11
1	99	19	80

The total number of species in these groups (excluding all repetitions) is 155.

The occurrences being 254, we have repetitions between group and group 99 out of 155; and, there being 16 groups, the average value of the fraction of distributiveness * $\frac{99}{155 \times 16}$.

* See Palæozoic Fossils of Devon, and Memoirs of Geological Survey, vol. ii., for example of this and other calculations.

Nearly all the species make their first *appearance* in one or other of the six lower groups (1 to 23 smaller groups). In the 14th great group 31 of the species are *disappearing*.

The Gault or Golt. (Syn. Blue Marl of Tetsworth and Folkstone, Micaceous Brick-earth, Smith.)—The gault or golt is an argillaceous member of the green sand group, of great interest to the conchologist; since in Kent, Surrey, Sussex, Wiltshire, Cambridgeshire, and Yorkshire it yields a most rich supply of molluscous remains, many of them minute and of the greatest beauty. It accompanies the lower green sand around the whole district of the Weald, separates the upper and lower green sand in the Isles of Wight and Purbeck, and follows with the same relations the range of the green iron sand through Wilts and Berks, Buckinghamshire and Bedfordshire, and Cambridgeshire; and appears in Yorkshire without either upper or lower green sands immediately below the chalk. Its average thickness may be fairly estimated at 100 feet, and it universally forms a characteristic narrow valley under the chalk. No remarkable peculiarity of mineralogical aspect or chemical composition distinguishes the gault, except a general tendency to admit green grains into its more sandy portions. It produces a capital brick-earth, fit for white bricks, in the midland counties. It is often of a very dark blue, but sometimes of a light gray colour. Near Folkstone it contains in the lower part a remarkable layer of small, irregular, ironstone nodules, every one of which is formed round an ammonite. A similar layer contains similar ammonites at Steppingley Park, Bedfordshire. At Speeton in Yorkshire oval nodules of similar nature generally enclose small specimens of astacidæ. Small belemnites, crioceratites, ammonites, nuculæ, striated terebratulæ, serpulæ, &c., abound in this gault, and serve admirably to complete the catalogues of fossils of the cretaceous system.

The Speeton clay is found immediately below the "red chalk," as that is covered by "white chalk." Neither upper nor lower green sand can be traced here. It does not appear distinctly divisible into two parts; yet the lower part, towards the coralline oolite, yields some Kimmeridge clay fossils. The upper part affords crioceratites, nuculadæ, and belemnites of the cretaceous group. The analogy of the upper part of this clay to the gault of Folkstone is admitted; but we think it also allied to the gryphitic and crioceratitic groups of the lower green sand in Dr. Fitton's section. In the catalogue of genera which follows, the Speeton clay is classed with the gault.

The Upper Green Sand.—The upper green sand was first examined in Wiltshire, where it consists of green, gray, and irony sands, immediately subjacent to the chalk, and affording passages for the collected water of that thick deposit downward to the gault. The green grains there assumed to be characteristic of these strata are

now known to occur in older sands (in calcareous grit, for instance), and in much more recent beds (as above the chalk frequently), yet still the greenness of the sands immediately below chalk is a curious general fact. They are, however, quite as often gray or even whitish, with a remarkable tendency in the grains to coalesce into meagre sandstone, sandy chert, and at length semi-transparent and chalcedonic chert. These effects are particularly to be observed among specimens of the sponges, and so called alcyonia, which abound in the green sand group. It is easy to understand how so variable a mass of sands placed immediately below the chalk, and clearly in many places (as at Havre) graduating into that calcareous rock, should in several instances become so cretaceous as to be hardly distinguishable from the chalk itself. This happens in Bedfordshire, where the Tattenhoe stone appears to be the representative of the upper green sand, in Surrey at Merstham, in Dorsetshire at Beer. Round the Weald of Surrey and Sussex, the malm rock, which is certainly coeval with the Wiltshire green sand (Murchison), and also with the Merstham firestone, occasionally shows many green grains, and at Beechy Head (Mantell) changes to nearly the ordinary type of the green sand of Wiltshire. From these considerations we are fully justified in regarding the upper green sand as intimately connected with the lower commonly argillaceous part of the chalk, just as the calcareous grit is with the coralline oolite, and the calciferous sand with the inferior oolite. In particular places, mechanical causes gave a predominance to its sandy character, and in others the abundance of organic exuviæ impressed it with a particular zoological type. This mode of viewing it exactly accords with its general character through France, where it is associated with the lower argillaceous chalk under the title of *glauconie crayeuse*. According to this classification, the upper green sand or firestone beds form a nearly continuous base for the chalk from Lynn to Dorsetshire, and round the whole of the Weald of Kent and Sussex, yielding organic remains at intervals. The thickness of this mass of sand is quite irregular, from a few feet near Cambridge to something about 100 feet in Blackdown.

Lower Chalk, or Chalk Marl.—Chalk marl may be viewed as the next step in the gradation of changes by which we are conducted from the green sand system to the true cretaceous type. It is, in fact, an argillaceous chalk, holding variable quantities of clay and sand, superimposed upon the green sand or malm rock, and gradually changing upwards to the lower chalk. It is, perhaps, observable on the western slopes of the Yorkshire wolds above the red chalk, but is distinctly traceable below nearly the whole range of the chalk hills from Lynn to Dorsetshire, and round the whole of the Weald, everywhere closely associated with, and indeed hardly separable from,

the malm rock or firestone, and often enclosing, as near Woburn and Folkstone, green grains and fossils of the true upper green sand.

Middle (or Lower) Chalk.—In England, generally, the lower half of the thick mass of chalk is harder, more jointed, and less divided by layers of flint nodules than the upper part. It is often of a grayer colour, and, to a certain extent, distinguishable by a different suite of organic remains. In particular, it appears to contain very few of the asteroidea, crinoidea, or echinoidea, not so many belemnites or terebratulæ, but, on the contrary, yields more ammonites, some hamites, trochites, and other fossils approaching to those of the green sand group below. But the mineralogical character of the lower part of the chalk is liable to great variations. In Yorkshire, three-fourths of the whole mass are hard, and the lower portions are as much traversed by layers of flint nodules, at pretty regular distances, as the upper parts. In the Dover cliffs, beds of soft cretaceous marl divide the chalk without flints into two portions, the upper one yellowish, hard, and containing numerous thin beds of organic remains, the lower one whiter, softer, often gritty at the top, enclosing masses of pyrites, but few organic remains. (W. Phillips, in *Geology of England and Wales.*)

The Upper Chalk.—The upper chalk is usually recognized in England by its whiteness, softness, numerous layers of flints at intervals of four to six feet, and abundance of zoophytic remains. Sponges of many kinds, small lamelliferous corals, millepores, crinoidea, asteroidea, echinoidea of very remarkable form, large inocerami, belemnites, and abundance of terebratulæ are the most frequent of its numerous fossils. The layers of flint nodules are exceedingly interesting, and throw light upon the mode of formation of the chalk. They are always found in the planes of stratification, generally irregular in figure, black or gray within, with traces of spongiferous bodies, shells, echini, or other organic bodies. The external crust is usually white and siliceous. The sponges also are often quite white and siliceous, and lodged in a cavity, left by the decay of part of their substance. The crusts of echini are usually, even when enveloped in flint, converted to calcareous spar, and belemnites retain their original radiated structure. Occasionally, as at Sudbury, the flint occurs in thin layers parallel to the stratification.

It seems probable that in the formation of the chalk from the decomposition of the sea water then holding lime and silica in solution, the carbonate of lime and silica fell to the bottom together, in quantities sufficient on each occasion to constitute a *bed* of chalk and flint, and that the latter substance was especially attracted by the organic remains then lying on or beneath the beds, so as to collect round the sponges, echini, &c., exactly as the oolitic matter has been collected round shells, the lias limestone round ammonites, the

carbonate of iron round ferns, &c. Analogous cases occur in the spongiferous cherts of the Portland oolite and coralline oolite; and we might perhaps venture to extend the same mode of reasoning to the case of chert nodules in carboniferous limestone, for these often (not so generally as in the case of flint) contain organic remains.

Pyrites is generally plentiful in the upper chalk, variously crystallized, and is not unfrequently associated with silica in the sponges which lie in chalk. It is in these cases generally decomposed near the surface into brown oxide of iron.

Flints are very often split or cracked in their native repositories, as if by contraction of the mass; and this sometimes, but less frequently, happens, when organic remains of a solid kind are enclosed in them. The most remarkable cases of this nature are described by Mr. Webster, in the dislocated upper strata of chalk in the Isle of Wight. All the flints in the layers which alternate with chalk are found broken in every direction into pieces of every size, which remain in their relative places enclosed within the cell of chalk, and showing no other signs of fracture than a fine line, as in shivered glass. On being removed from their place, the flints fall into many pieces. This singular fact seems connected with the disturbances of the chalk, and may, perhaps, be due to the violence of the tremor then impressed upon the mass, a tremor which might shiver elastic flint (especially if, like, a Rupert's drop, its particles had been previously in a state of tension), but leave the chalk unaffected.

The thickness of the chalk in England is seldom less than 500 feet, and rarely so much as 1,000 feet. In the Isle of Wight, however, the section at Culver cliff seems to give as much as 1,200 feet. It has been estimated indeed by Mr. Greenough at 1,300 feet. The ammonites, turrilites, scaphites, crioceratites, &c., which abound in the lower parts, scarcely reach the upper part; while belemnites mucronatus, and ananchytes ovata, scarcely appear in the middle and lower groups.

Range of the Cretaceous System out of England.

The principal range of the cretaceous rocks is included within the general boundaries of the European basin, and it is probably not at all less extensive than the oolitic system, though by the diffusion of tertiary rocks above it, its course in large tracts of country is wholly subterranean.

Ireland.—The cretaceous system of Ireland is in a depression, on the western side of what is usually understood by the basin of Europe. It consists of chalk 200 or 300 feet thick, harder than is common in England, but with a similar though less extensive suite of organic remains, and rests on green sand, there called *mulatto*, with the usual characters of that group in England. Lias is found

beneath at the Giant's Causeway. In Scotland, only a dubious indication of the former extent of the cretaceous system is afforded by the flints which rest upon primary rocks near Peterhead.

Within the natural modern boundaries of the principal basin of European secondary strata—the primary rocks of Scotland, Cumberland, Wales, Cornwall, and Brittany, on the west; the Pyrenees, the Alps, and the Carpathians, on the south; Caucasus and Oural on the east; Finland and Scandinavia on the north—the cretaceous system, chalky, marly, or sandy, is very largely developed. The type of the formation may be taken in Southern England or Northern France indifferently. In the latter country its extent on the surface is probably equal to the whole superficial area which it occupies elsewhere in Europe. It encircles with a broad belt the basin of Paris, and passes off on the north-eastern side into Belgium, which whole country it probably underlies, though the tertiary deposits conceal it, except along the sides of the Meuse. At Maestricht the upper beds of the cretaceous formation have, in many respects, mineralogical and organic, a remarkable analogy to the *calcaire grossier*, which is the lowest really marine tertiary rock in the vicinity. These beds, however, by their principal character really belong to the cretaceous system, of which they may be considered the highest terms at present known. A little appearance of the chalk is observable north of the coal of Elberfeld, to which it is unconformed, as well as to that of Namur and Liege. The chalk system most probably underlies the whole region of Northern Germany, from the point last mentioned north of the oolite and lias of Westphalia. The green sand is remarkably well exhibited with characteristic fossils in the romantic tract of Saxony, north of the Erzegebirge (there called *quadersandstein*), as well as an upper calcareous portion supposed equivalent to the chalk and called planerkalk. North of the Carpathians both chalk and green sand occur in long ranges of hills, passing from Poland by Lemberg into Podolia and the south of Russia. It reaches the Dniester, and extends to the plains of Volhynia. It forms considerable eminences around Grodno in Lithuania. "Farther south, in the plains of Moldavia, Podolia, and Bessarabia, it appears only in detached portions. Chalk is found on the southern side of the granitic steppe in the Crimea, and on the borders of the Sea of Azof, between the Berda and the Don. In the country of the Don Cossacks, in the governments of Woronack, Koursk, and Toula, it appears in hills and on the banks of rivers, and probably constitutes the base of that great and fertile plain."—(Pusch, quoted by De la Beche, *Manual of Geology*.)

In Pomerania and Mecklenburg, and the Island of Rugen, cliffs of chalk occur with the usual fossils of England, and in Sweden it rests upon rocks of gneiss and greywacke, and only in one instance, at

Limhamm in Scania, upon rocks of the oolitic era. In the north of Germany it appears at intervals, near Luneburg, and on the borders of the Harz mountains (at Quedlinburg); and there seems no reason to doubt that the whole vast plain of Northern Germany, from the Rhine to the Vistula, rests upon the cretaceous system. What remains of the Island of Heligoland consists of green sand.

The whole line of the Alps from the Salève to Vienna is bordered upon the northern side by rocks of the cretaceous system, which are closely associated in character both with the oolites beneath and with the tertiaries which lie above. A similar observation applies to the south side of these mountains. Rocks of this era range down the Apennines, and occur abundantly in the Maritime Alps, there, as well as about Geneva, intimately associated with the upper oolitic beds. Deposits of this age also lie in old valleys of the Jura mountains, which range in a north-eastern and south-western direction. The Pyrenees are bordered on both sides by green sand and sandy and calcareous beds, containing with many chalk fossils some of tertiary types.

Over this extensive area the mineralogical characters of the system are tolerably uniform, except in the vicinity of the Alps, where the violent disturbances to which that mountain range has been subjected appear to have entirely altered the aspect of these beds, so as to permit authors to speak of *black chalk*, which, however, is really a portion of the green sand group. Over all the region already mentioned in France, in Belgium, at all the points in Northern Germany, in Poland, in Russia, Pomerania, Denmark, and Sweden, the chalk has its usual characters and appearance, and contains ananchytes and spatangi, belemnites, terebratulæ, inocerami, &c. The green sand in France, near Aix-la-Chapelle, along the Erzgebirge, in Poland, along the Carpathians, in Heligoland, has its usual characters. Indeed, even along the Eastern Alps, but especially in the Swiss and Savoy Alps, and the Jura, the green sand group retains nearly its usual aspect, and exhibits its usual fossils; and an English geologist placed at the Perte du Rhone, or amidst the relics of the Montagne de Fiz, is at once introduced to the geology of the vicinity. Green sand layers alternate with the upper part of the Jura oolites in the Salève, and the same phenomenon appears to happen along the Eastern Alps (Murchison's and Sedgwick's Memoirs, *Geological Transactions*), where some parts of this group contain fuci so as to be characterized thereby. In the Maritime Alps the lower beds of the cretaceous formation consist of light coloured limestone charged with green grains, and full of belemnites, ammonites, nautili, and pectines, and appear intimately connected with the top of the Jura limestone deposit.*

* De la Beche, *Manual*, 259.

On the southern side of the Alps the beds of the cretaceous era, which descend to the plains of Lombardy, are principally composed of white, greenish, and reddish beds, and it appears that a gradation of character may be traced through the oolitic, cretaceous, and tertiary strata here uplifted. (Murchison.) Some of the light coloured limestones referred to the chalk are called scaglia, and the mountain of the Voirons near Geneva yields a rock of similar nature.

Dislocations of the Cretaceous System.

Like the oolitic era, the cretaceous period appears to have been one of regular action, perhaps still more uniform than that, but not of so long duration. For we do not find its deposits to contain so many distinct suites of organic remains, nor so many remarkable *repetitions* of analogous rocks as occur in the oolitic system. The lower sandy beds of the system, indeed, may be thought to have been influenced by the convulsions which upheaved the oolites, but we cannot assent to the notion that the whole cretaceous system is derived from the mechanical movements thus impressed upon the waters. The organic remains of the system sufficiently disprove this, and the great extent and uniformity of the deposit of chalk is no otherwise to be explained than by general laws applicable to all the older and more recent calcareous strata.

That disturbances of great extent happened *somewhere* after the deposit of the chalk in England, is evident from the extraordinary abundance of sandy and gravelly accumulations, sometimes resting in hollows of the chalk, which immediately cover that stratum. A great part of the plastic clay group is of this fragmentary and tumultuary origin, and its black flint pebbles are only water-worn chalk flints. But England does not appear to have been the centre of these convulsions, nor to have been much moved by them unless bodily, and without local and violent fracture of strata. It is, indeed, very *probable*, that parts of the chalk formation, originally deposited in deeper seas, were at this time brought up and made to constitute a shore and to be liable to all the waste of the waves. And some portions might be, and probably were, raised to dry land, and exposed to the weather and the wearing of streams. But we can seldom at present undertake to say where such a shore occurred, or in what part exactly the chalk was raised into hills.

In Ireland, at this period, great eruptions of basalt happened, and broad lakes of lava covered the chalk of that country.

In France the chalk was wasted as in England, and its flints rolled to pebbles, to constitute the pebbly beds of the plastic clay group; and this seems to have been chiefly effected by fresh water streams, for we find in the plastic clay of France few organic remains besides

terrestrial and fresh water productions. Yet here, we believe, it is equally difficult to say what *portions* of the chalk were thus raised and exposed. The surface of the chalk in France appears to have been even more wasted, furrowed, and pitted than in England.

To this period Elie de Beaumont ascribes the dislocations which in the French Alps and the south-western extremity of the Jura, from the environs of Antibes to those of Pont d'Ain and Lons le Saulnier, present a series of dislocations in a direction north north-west. The primary mass of Mont Viso is traversed by this system of faults. The eastern crests of the Devolny, on the north of Gap, are formed of the oldest beds of the green sand and chalk, thrown up in the direction north north-west, and raised more than 4,700 English feet above the sea, while at their feet, and 2,000 feet lower, the upper portion of the cretaceous system remains horizontal and entirely undisturbed.

Everything belonging to this particular epoch, that is calculated to throw light on the changes then operated on the external features of the globe is of the highest curiosity and importance, since the probability is great that very violent and extensive convulsions, producing most remarkable alterations in physical geography and in other conditions of organic life, must have happened to occasion so entire and rapid a change of plants, shells, and vertebrated animals, as, notwithstanding recent discoveries of supposed intermediate strata, is admitted to have taken place after the deposition of the cretaceous system.

Some time after the above remarks were written, the third volume of the *Principles of Geology* (1st edit.) appeared, in which the able author ventured to do what we then thought too difficult to attempt, and define in one instance what part of the ancient bed of the sea was raised at the commencement and during the continuance of the tertiary period. Combining his own observations on tertiary strata with Mantell's discoveries, he proposed the theory that the elevation of the Wealden district of Sussex and Kent was contemporaneous with, or only immediately antecedent to, the deposition of the tertiaries in those parts of the sea which are now become the basins of London and Hampshire; that the elevation of the secondary, as well as the deposition of the tertiary rocks, was produced by long continued operations of the same kind; and that as different strata were raised in the Weald, to be wasted away by the sea and atmospheric action, the tertiary deposits, thence carried to the depths of the sea, were proportionately varied. We cannot now discuss this ingenious theory, because it is connected with a very extensive argument, involving many of the fundamental views of this author, Elie de Beaumont, and Von Buch, but the subject will be examined in its proper place.

ORGANIC REMAINS OF THE UPPER MESOZOIC STRATA.

PLANTS.

ALGÆ.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Confervites, . .	3	...	...	...	...	3
Chondrites, . .	2	2	...	...	...	...
FILICINÆ.						
Lonchopteris, . .	1	1	...	...	...	...
LILIACEÆ.						
Dracæna, . . .	1	...	...	1	...	...
CYCADEÆ.						
Zamiostrobus, . .	3	1	...	2	...	...
Clathraria, . . .	1	...	...	1	...	...
CONIFERÆ.						
Abietites, . . .	2	1	...	1	...	...
Strobilites, . . .	1	...	...	1	...	...

AMORPHOZOA.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Achilleum, . .	1	...	...	...	...	1
Brachiolites, . .	10	...	...	...	4	6
Cephalites, . . .	12	...	...	...	...	12
Chenendopora, . .	7	...	...	5	...	2
Choanites, . . .	1	...	...	...	...	1
Cliona, . . .	3	...	...	...	...	3
Cnemidium, . .	2	...	...	2	...	...
Coeloptychium, . .	1	...	...	...	...	1
Conis, . . .	1	1	...	...	...	...
Coscinopora, . .	5	...	...	...	...	5
Guettardia, . .	1	...	...	...	1	1
Hippalimus, . .	2	...	...	1	...	1
Ierea, . . .	4	...	...	4	...	...
Manon, . . .	6	...	...	3	1	3
Paramoudra, . .	1	...	...	...	...	1
Plocoscyphia, . .	3	...	...	3	...	...
Polypothecia, . .	5	...	...	2	...	3
Scyphia, . . .	10	...	...	6	...	4
Siphonia, . . .	8	...	...	3	...	5
Spongia, . . .	11	...	...	1	1	9
Talpina, . . .	3	...	...	...	...	3
Udotea, . . .	1	...	...	...	...	1

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Ventriculites, . .	13	...	...	...	...	13
Verticillites, . .	2	...	...	1	...	1
Xanthidium? . .	14	...	...	...	...	14

FORAMINIFERA.

Bulimina, . . .	8	...	1	1	1	8
Cristellaria, . .	6	...	3	1	1	6
Dentalina, . . .	13	...	3	...	1	12
Flabellina, . . .	8	...	...	...	...	8
Frondicularia, . .	7	...	3	...	...	...
Gaudryina, . . .	3	...	2	...	...	2
Globigerina, . .	3	...	...	1	1	2
Guttulina, . . .	1	...	...	1	...	...
Lingulina, . . .	1	...	...	...	...	1
Lituola, . . .	1	...	...	...	...	1
Marginularia, . .	6	...	1	...	...	5
Nodosaria, . . .	7	...	2	1	...	7
Orbitolina, . . .	2	...	...	2	...	...
Planulina, . . .	1	...	...	...	...	1
Pyrulina, . . .	1	...	...	...	...	1
Quinqueloculina, . .	1	...	1	...	...	1
Rosalina, . . .	8	...	2	1	...	8
Rotalina, . . .	11	...	3	1	...	11
Sagrena, . . .	1	...	...	...	...	1
Spirillina, . . .	2	...	...	...	...	2
Spirolina, . . .	2	...	1	...	1	1
Textularia, . .	10	...	1	...	1	10
Truncatulina, . .	1	...	...	1	...	1
Vaginulina, . .	3	...	2	...	...	3
Verneuillina, . .	2	...	1	...	1	2
Webbina, . . .	1	...	...	...	...	1

ZOOPHYTA.

Axogaster, . . .	1	...	...	...	...	1
Bathycyathus, . .	1	...	1	...	...	...
Coelosmilia, . .	1	...	...	...	...	1
Cyathina, . . .	1	...	1	...	...	...
Diblasus, . . .	1	...	...	...	...	1
Epiphaxum, . .	1	...	...	...	...	1
Holocystis, . . .	1	1	...	...	...	...
Micrabacia, . .	1	...	...	1	...	...
Parasmilia, . .	6	...	...	...	...	6
Parastræa, . . .	1	...	...	1	...	...
Peplosmilia, . .	1	...	...	1	...	...
Siphodictyum, . .	1	1	...	...	...	...
Smilotrochus, . .	1	...	...	1	...	...
Spinopora, . . .	1	...	...	...	...	1
Stephanophyllia, . .	3	...	...	...	2	1
Synhelia, . . .	1	...	...	...	1	...
Trochocyathus, . .	4	...	4	...	...	...
Trochosmilia, . .	2	...	1	1	...	...

ECHINODERMATA.

ECHINOIDEA.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Ananchytes, . .	1	...	...	...	...	1
Caratomus, . .	1	...	...	1	...	...
Cardiaster, . . .	9	1	1	3	...	5
Catopygus, . . .	1	...	...	1	1	...
Cidaris, . . .	12	...	2	1	1	8
Cyphosoma, . .	7	...	...	...	...	7
Diadema, . . .	16	3	...	10	5	...
Discoidea, . . .	5	1	...	2	3	2
Echinopsis, . . .	1	...	...	...	...	1
Echinus, . . .	3	1	...	2	...	...
Galerites, . . .	6	...	...	1	2	4
Goniopygus, . .	1	...	...	1	...	...
Hemiaster, . . .	5	...	3	1	1	...
Hemipneustes, . .	2	1	...	1	...	...
Holaster, . . .	5	...	...	1	4	1
Micraster, . . .	4	...	...	...	2	3
Nucleolites, . .	5	2	...	3	...	...
Pygurus, . . .	1	...	...	...	1	...
Pyrina, . . .	2	...	...	...	2	...
Salenia, . . .	12	1	...	5	6	1

ASTEROIDEA.

Arthraster, . . .	1	...	...	...	...	1
Goniaster, . . .	17	...	...	2	5	11
Oreaster, . .	7	...	...	...	1	6

OPHIURIDEA.

Ophiura, . . .	1	...	...	...	...	1

CRINOIDEA.

Bourguetocrinus, . .	5	...	...	...	1	4
Glenotremites, . .	1	...	...	...	1	...
Marsupites, . .	3	...	...	...	...	3
Pentacrinus, . .	2	1	1	...	...	1

ANNELIDA.

Serpula, . . .	24	1	1	6	3	15
Vermicularia, . .	5	2	1	3	...	...
Vermilia, . . .	4	...	...	1	...	3

CIRRIPEDA.

Loricula, . . .	1	...	...	...	1	...
Pollicipes, . . .	9	1	3	1	2	4
Scalpellum, . .	10	1	1	...	3	8
Verruca, . . .	1	...	...	...	...	1

CRUSTACEA.

ENTOMOSTRACA.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Bairdia, . . .	6	1	2	2	1	4
Cythere, . . .	4	1	1	1	2	3
Cythereis, . . .	8	2	6	2	...	7
Cytherella, . .	6	...	3	...	3	5
Cytheridea, . .	1	...	1	1	1	1

MALACOSTRACA.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Enoploclytia, . .	4	...	...	...	4	...
Etyus, . . .	1	...	1	...	...	...
Grapsus, . . .	1	...	...	...	1	...
Holoparia, . . .	1	...	1	1	...	...
Mesostylus, . .	1	...	...	...	...	1
Meyeria, . . .	3	1	3	...	...	...
Notocorystes, . .	4	...	3	1	...	...
Pagurus, . . .	1	...	...	...	...	1
Palinurus, . . .	1	...	1	...	...	...
Platypodia, . .	1	...	...	...	1	...
Podopilumnus, . .	1	...	...	1	...	...

BRYOZOA.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Actinopora, . .	5	...	...	1	...	4
Alecto, . . .	2	...	...	...	...	2
Atagma, . . .	1	...	...	...	...	1
Cellepora, . . .	2	...	...	...	...	2
Ceriocava, . . .	2	...	...	2	...	...
Ceriopora, . . .	3	...	...	2	1	1
Clypeina, . . .	1	...	...	...	...	1
Cricopora, . . .	3	...	...	1	...	2
Desmeopora, . .	1	...	...	...	...	1
Diastopora, . .	9	...	...	4	...	5
Discopora, . . .	2	...	...	...	...	2
Domopora, . . .	1	...	...	1	...	...
Entalophora, . .	5	...	...	5	...	...
Eschara, . . .	4	...	...	...	...	4
Escharina, . . .	2	...	...	...	...	2
Flustra, . . .	4	...	...	...	...	4
Heteropora, . .	2	1	...	1	...	2
Hippothoa, . .	1	...	...	...	...	1
Holostoma, . .	1	...	...	...	...	1
Homœosolen, . .	1	...	...	...	...	1
Hornera, . . .	1	...	...	...	...	1
Idmonea, . . .	5	...	...	...	...	5
Lunulites, . . .	1	...	...	...	...	1
Marginaria, . .	1	...	...	...	...	1
Multicrescis, . .	2	...	1	2	...	...
Petalopora, . .	1	...	...	...	...	1
Proboscina, . .	2	...	...	2	...	...
Pustulopora, . .	4	...	...	1	...	3

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Radiopora, . . .	1	...	...	1	...	...
Reptocea, . . .	1	...	...	1	...	...
Reptomulticava, . .	3	...	...	3	...	...
Reptotubigera, . .	2	...	...	2	...	...
Retepora, . . .	2	...	...	1	...	1
Siphoniotyphlus, . .	1	...	...	...	...	1
Vincularia, . . .	1	...	...	...	...	1
Zonopora, . . .	1	...	...	...	...	1

BRACHIOPODA.

Argiope, . . .	2	...	...	1	...	1
Crania, . . .	4	...	...	2	...	3
Discina, . . .	1	1	...	...	...	...
Lingula, . . .	2	2	...	...	...	...
Magas, . . .	1	...	...	...	1	1
Rhynconella, . .	19	4	3	7	5	6
Terebratella, . .	7	1	1	4	3	4
Terebratula, . .	28	7	1	14	8	4
Terebratulina, . .	2	...	1	1	2	2
Thecidium, . . .	1	...	...	1	...	1

MONOMYARIA.

Anomia, . . .	4	4	...	...	...	...
Avicula, . . .	7	4	...	3	...	...
Exogyra, . . .	9	3	4	4	2	4
Gervillia, . . .	5	4	1	1	1	...
Gryphæa, . . .	1	...	...	1	...	1
Inoceramus, . .	21	1	2	5	10	7
Lima, . . .	26	7	2	11	8	2
Ostrea, . . .	17	3	1	5	3	11
Pecten, . . .	28	7	1	12	9	8
Perna, . . .	4	2	1	1	...	...
Pinna, . . .	8	2	1	3	...	2
Spondylus, . . .	8	1	...	2	2	4
Vulsella, . . .	1	...	...	...	...	1

DIMYARIA.

Amphidesma, . .	1	...	...	1	...	...
Anatina, . . .	2	...	1	1	...	...
Arca, ...	8	4	...	3	1	...
Astarte, . . .	11	4	1	5	1	...
Cardita, . . .	3	2	1	...	...	...
Cardium, . . .	14	10	...	4	...	...
Corbis, . . .	1	1	...	...	...	...
Corbula, . . .	4	1	1	2	...	...
Crassatella, . . .	1	1	...	...	...	...
Cryptodon, . . .	1	...	1	...	...	...

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Cucullæa, . . .	6	2	1	4	...	...
Cypricardia, . .	1	1	...	...	...	...
Cyprina, . . .	5	1	...	5	...	...
Cytherea, . . .	6	1	1	5	...	...
Diceras, . . .	1	...	...	1	...	...
Gastrochæna, . .	2	1	1	...	...	...
Isocardia, . . .	3	2	1	...	...	...
Leda, . . .	4	2	...	1	1	...
Lithodomus, . .	2	2	...	...	...	...
Lucina, . . .	6	3	1	2	...	...
Lutraria, . . .	2	...	...	1	1	...
Mactra, . . .	1	...	...	1	...	...
Modiola, . . .	7	5	...	1	1	...
Mya, ...	2	...	1	1	...	...
Myacites, . . .	8	6	1	2	...	...
Mytilus, . . .	6	1	1	4	...	...
Neæra, . . .	1	...	1	...	...	...
Nucula, . . .	11	4	5	4	...	...
Opis, ...	1	...	...	1	...	...
Pachyma, . . .	1	...	...	1	...	...
Pectunculus, . .	2	...	1	2	...	...
Petricola, . . .	2	...	...	2	...	...
Pholadomya, . .	5	3	...	1	1	...
Pholas, . . .	2	1	1	...	...	...
Psammobia, . .	1	...	...	1	...	...
Radiolites, . . .	2	...	...	1	1	...
Solecurtus, . . .	1	1	...	...	...	...
Sphæra, . . .	4	1	...	...	...	...
Tellina, . . .	4	2	...	2	...	...
Teredo, . . .	2	...	...	...	1	2
Thetis, . . .	4	1	...	3	...	...
Thracia, . . .	2	1	1	...	...	...
Trigonia, . . .	15	6	...	11	...	...
Venus, . . .	10	6	1	3	...	...

GASTEROPODA.

Actæon, . . .	5	2	2	...	1	...
Avellana, . . .	6	...	3	1	1	1
Cassidaria? . .	1	...	...	...	1	...
Cerithium, . . .	7	6	1	...	...	...
Delphinula, . .	1	...	1	...	...	...
Dentalium, . .	6	1	3	3	1	...
Dolium? . . .	1	...	...	...	1	...
Emarginula, . .	3	1	...	...	2	...
Eulima, . . .	2	1	...	...	1	...
Fusus, . . .	4	...	...	4	...	...
Hipponyx, . . .	1	...	...	...	...	1
Littorina, . . .	7	2	...	7	...	...
Murex, . . .	1	...	1	1	...	...
Nassa, . . .	1	...	...	1	...	...
Natica, . . .	8	2	3	4	...	...
Nerinæa, . . .	1	...	...	...	1	1
Phasianella, . .	4	...	...	4	...	...

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Pleurotomaria, . .	6	2	1	1	1	1
Pterocera, . . .	4	3	...	1	...	...
Pterodonta, . .	1	...	...	1	...	...
Pyrula, . . .	3	...	1	2	...	...
Rostellaria, . .	9	2	6	3	...	...
Solarium, . . .	7	2	3	3	1	...
Trochus, . . .	3	2	...	...	1	...
Turbo, . . .	6	2	1	...	3	...
Turritella, . . .	5	1	1	2	1	...
Tylostoma, . .	1	...	...	...	1	...
Bellerophina, . .	1	...	1	...	...	...

CEPHALOPODA.

Ammonites, . .	71	7	29	20	24	3?*
Ancyloceras, . .	8	4	4	...	...	...
Baculites, . . .	3	...	...	...	1	2
Belemnitella, . .	4	...	...	...	2	3
Belemnites, . .	5	...	5	...	2	...
Crioceras, . . .	3	1	2	...	...	...
Hamites, . . .	15	1	11	2	4	...
Helicoceras, . .	1	...	1	...	...	...
Nautilus, . . .	17	7	1	3	11	1
Ptychoceras, . .	1	...	1	...	...	...
Scaphites, . . .	2	...	...	1	2	...
Turrilites, . . .	11	...	4	...	7	...

PISCES.

PLACOIDEI.

HYBODONTIDÆ.

Hybodus, . . .	3	1	...	...	1	2

CESTRACIONTIDÆ.

Acrodus, . . .	3	...	...	...	...	3
Aulodus, . . .	1	...	...	...	...	1
Cestracion, . . .	1	...	...	...	...	1
Plethodus, . . .	2	...	...	...	...	2
Ptychodus, . .	15	...	1	...	...	14
Strophodus, . .	2	1	...	...	...	1

LAMNIDÆ.

Lamna, ...	2	...	...	...	...	2
Odontaspis, . .	1	...	...	...	...	1
Oxyrhina, . . .	2	...	...	...	...	2
Scylliodus, . . .	1	...	...	...	...	1

NICTITANTES.

Corax, . . .	2	...	...	...	...	2

* In Ireland.

EDAPHODONTIDÆ.

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
Edaphodon,	3	...	...	1	...	2
Ischyodon,	2	...	1	...	1	...

NOTANIDÆ.

Notidanus,	2	...	...	...	...	2

SQUALIDÆ.

Orodus,	2	...	...	...	...	2

GANOIDEI.

SAUROIDEI.

Lophiostomus,	1	...	...	...	...	1
Belonostomus,	2	...	...	...	...	2
Caturus,	1	...	...	...	...	1
Pomognathus,	1	...	...	...	...	1

PYCNODONTIDÆ.

Pycnodus,	4	...	...	...	1	3
Acrotemnus,	1	...	...	...	...	1
Gyrodus,	5	...	1	...	...	4
Microdon,	2	...	...	...	...	2
Phacodus,	2	...	...	...	...	2

LEPIDODEI.

Lepidotus,	1	...	...	...	...	1

COILACANTHI.

Macropoma,	3	...	...	1	...	2

PLECTOGNATHI.

Dercetis,	1	...	...	...	...	1

GYMNODONTIDÆ.

Orthagoriscus,	1	...	...	...	1	...

CYCLOIDEI.

SALMONIDÆ.

Acrognathus,	1	...	...	...	1	...

SCOPELIDÆ.

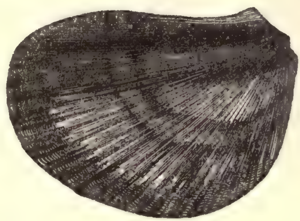
Osmeroides,	4	...	...	...	...	4
Tomognathus,	2	...	...	...	...	2

	No. of Species.	L. Green.	Gault.	U. Green.	L. Chalk.	U. Chalk.
SCOMBERIDÆ.						
Coelorhynchus, . .	1	...	...	...	...	1
Enchodus, . . .	1	...	...	...	...	1
Tetrapterus, . .	1	...	...	...	...	1
MUGILIDÆ.						
Calamopleurus, . .	1	...	...	...	...	1
SPHYRENIDÆ.						
Cladocyclus, . .	1	...	...	...	...	1
Hypsodon, . . .	2	...	...	...	...	2
Saurodon, . .	1	...	...	...	..	1
Pachyrhizodus, . .	1	...	...	...	...	1
Saurocephalus, . .	2	...	...	...	...	2
CTENOIDEI.						
PERCIDÆ.						
Berycopsis, . . .	1	...	...	...	...	1
Beryx, ...	4	...	...	...	...	4
Stenostoma, . .	1	...	...	...	...	1
Homonotus, . .	1	...	...	...	...	1
REPTILIA.						
DINOSAURIA.						
Iguanodon, . . .	1	...	...	...	...	...
CROCODILIA.						
Polyptychodon, . .	2	1	...	1	1	1
LACERTILIA.						
Coniosaurus, . .	1	...	...	...	...	1
Dolichosaurus, . .	1	...	...	...	1	...
Leiodon, . . .	1	...	...	...	...	1
Mosasaurus, . .	1	...	...	...	...	1
Raphiosaurus, . .	2	...	...	...	1	1
ENALIOSAURIA.						
Plesiosaurus, . .	4	1	...	1	2	...
Ichthyosaurus, . .	1	...	...	...	1	...
PTEROSAURIA.						
Pterodactylus, . .	4	...	...	...	4	...
CHELONIDA.						
Chelone, ...	4	...	...	1	1	2
Protemys, . . .	1	1	...	...	...	...

LOWER GREEN SAND FOSSILS.

278

279



280

281

282

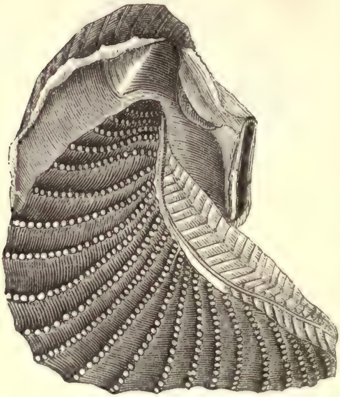
283

278 Spatangus retusus.
279 Exogyra subplicata.
280 Lima elegans.

281 Requienia (Diceras) ammonia.
282 Crioceratites Duvallii.
283 Ancyloceras.

284

285



286

287

284 Ptychoceras.
285 Hamites.

286 Trigonia caudata.
287 Exogyra sinuata.

GAULT FOSSILS.

288

289

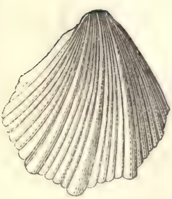
290

288 Inoceramus sulcatus.

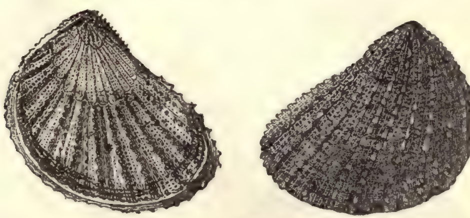
289 Inoceramus concentricus.

290 Nucula pectinata.

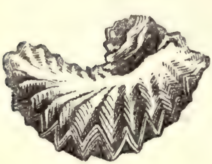
UPPER GREEN SAND FOSSILS.



291



292



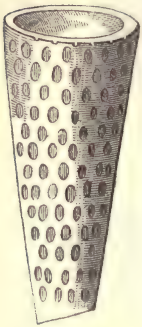
293

294

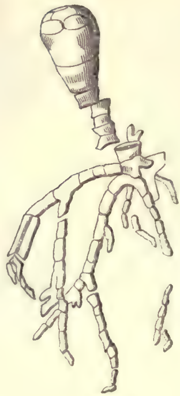
291 Pecten quinquesulcatus.
292 Plicatula placunea.

293 Ostrea carinata.
294 Trigonia alæformis.

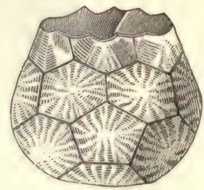
CHALK FOSSILS.



295



296



297

298

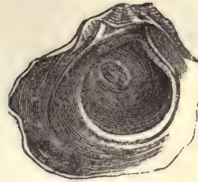
299

295 Spongia cribrosa.
296 Apiocrinus ellipticus.
297 Marsupites ornatus.
298 Ananchytes ovatus.
299 Spatangus coranguinum.

300

301

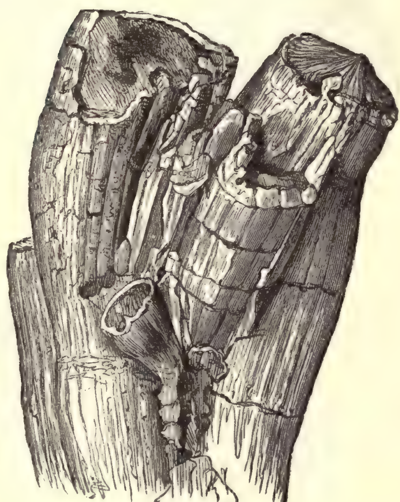
302



303

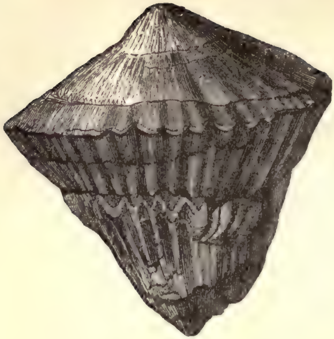
304

305

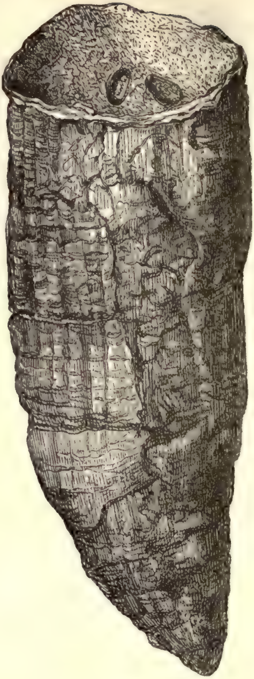


306

300 Terebratula Defrancii.
301 Rhynconella octoplicata.
302 Exogyra columba.
303 Ostrea vesicularis.
306 Hippurites organisans.
304 Plagiostoma spinosum.
305 Inoceramus Cuvierii.

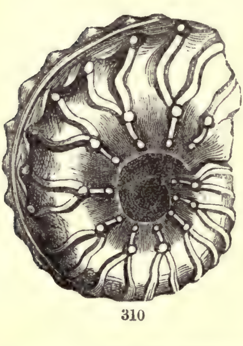


307



308

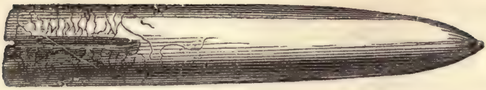
309



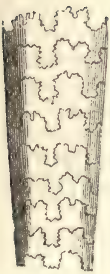
310

311

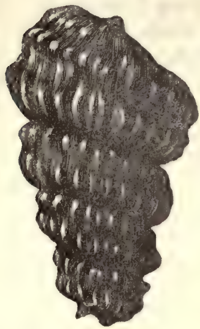
307 Spherulites ventricosa or Radiolites turbinata.
308 Hippurites bioculata.
309 Ammonites monilis.
310 Ammonites varians.
311 Ammonites rothomagensis.



312

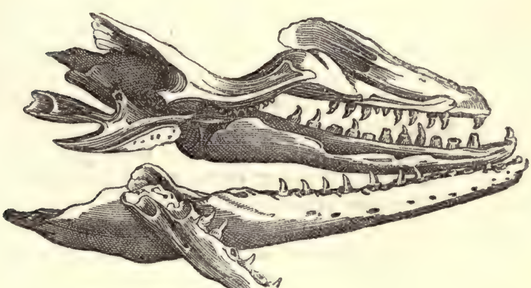


313



314

315



316

312 Belemnites mucronatus.
313 Baculites Faujasii.
314 Turrilites costatus.
315 Scaphites æqualis.
316 Head of Mosasaurus of Maestricht.

CHAPTER XII.

CAINOZOIC STRATA.

We have now arrived at the last system of strata deposited in the sea and in lakes; before, as is usually stated, the present races of land animals and plants were called into existence. It is usually stated to be limited as to time between the era of the chalk and the beginning of the modern zoological period; but this definition is something arbitrary in application. As we have seen, on previous occasions, the several systems of strata, however distinct in the great mass, gradually soften into each other at the lines of junction, and sometimes exchange beds, so as to form the whole into a natural and connected series, so it may be with the present set of deposits in relation to the chalk. In England, indeed, as already remarked, this kind of *transition* from the chalk to the tertiaries, is nowhere distinct, nor are we entitled to say decidedly that at any point on the Continent of Europe it is completely ascertained.

The blending, however, of tertiary and cretaceous rocks would, if established at many points, occasion no peculiar difficulty in their arrangement, nor alter one just inference drawn from previous observations. It is to be expected, from everything that is known of similar cases, that the great and abrupt change between the chalk and tertiaries in England and in France will be in some other countries divided into easier gradations, and thus the maxim *natura non facit saltus*, will be found to prevail in this case as in all others.

A greater difficulty, however, occurs when we attempt to mark the *modern limit* of the tertiary system of strata, arising out of several circumstances important in their history, which scarcely required notice amongst the older deposits.

The ancient systems of strata were for the most part marine; but the tertiary system includes many estuary and lacustrine deposits, which sometimes alternate with the marine strata, sometimes appear unconnected with them, and in several instances were evidently altogether independent of them and of each other, being formed separately upon the elevated lands under the influence of the ordinary processes of drainage. Now as similar causes have been in operation long since the tertiary era, and are in operation at present, it is often for this reason very difficult to say what is really the geological antiquity of a lacustrine deposit, whether it be of the present period, or belonging to the tertiary or some intermediate system.

Within the tertiary era a variety of land mammalia came into existence which are now extinct, and which it appears had become

extinct before the glacial detritus was scattered, and the elephant and hyæna were destroyed in northern climes. Taken in order of time, we may mark with some confidence, at least two characteristic groups of terrestrial life, by the older Palæotherian and the less ancient Mastodontoidal or Elephantoidal races. The former belong to the lower groups of tertiary strata, those called by Lyell *Eocene*, as formed at the dawn of the recent period. The latter occur in his *Meiocene* and *Pleiocene* groups, in which the analogy to existing nature grows stronger and stronger till it becomes a real and intimate affinity in the *Pleistocene* deposits. In a few cases palæotherian and mastodontic remains occur together, and help to prove that the changes from the earlier to the latter system of organic nature were, like all the preceding, gradually accomplished; that before the palæotheria had become extinct, the ox, mastodon, and rhinoceros had begun to exist.

The tertiary class is often stated to include only the deposits which happened before the present system of organic nature was established. But do geologists really admit what these words imply? We who have used these terms, and have come to reflect on their meaning, answer certainly not, either in theory or in practice. For the *present system of organic nature* is most certainly recognized in nearly all the marine tertiary strata, if we trust to the evidence which in every other such case has been thought the best: *viz.* the marine shells. The shells of all the tertiary marine strata are proved by various degrees of evidence to belong to the present *system* of organic nature, for the genera are almost universally the same, though the numerical analogy of the species is very unequal in different deposits.

Neither is it true, that what are called lacustrine tertiaries can in all cases be pronounced to contain exuviæ of another system of organic nature: for if this could hardly be asserted of the basin of Paris, what is to be said of Aix and Œningen?

It can hardly be doubted that the land accumulations are capable of being classed by the reliquiæ of land animals which they contain; and this classification is helped in northern zones by the striking phenomena of the glacial era, which separate into two groups the more recent postglacial, from the more ancient preglacial quadrupeds. As these remains lie often in lacustrine, and sometimes in marine sediments, which contain shells and other forms of life, the phenomena of land-life became comparable with those of the waters, and thus with proper caution the laws of succession of life forms become of general application.

To be consistent, however, we must certainly allow that the races of land animals might be altogether changed without any corresponding change of lacustrine or marine shells, and we must limit our classifications to their just application. We must judge of the age

and other characters of supracretaceous marine strata by comparison with what is known of the modern condition of the sea; the lacustrine deposits of the same era must be compared to the standard of the modern lakes; and the terrestrial accumulations will derive illustration from comparison with the modern state of the land, and the aqueous agencies upon it. In some instances at present, and it is to be expected that hereafter many more will be established, the relative epochs of certain terrestrial, lacustrine, and marine phenomena have been determined, but it is not the less certain that these phenomena belong to three independent series, which must be studied apart before they can be understood together.

It must be evident, from what has been said before, that a considerable proportion of the old strata had at the commencement of the tertiary system been raised above the sea, some parts by violent, others by gentle and continued elevation. In the latter way, we imagine, the chalk and oolites of England to have been a little raised above the sea at this period, so as to leave broad planes of the chalk rising gradually from the sea, and, of course, exposed to the violence of its waves, and other parts dry and fit for the growth of plants and the residence of animals. In France the same effects may be supposed to have happened round the greater part of the basin of Paris, while the old granitic rocks of central France had some time before raised themselves to nearly their present altitude, and constituted a shore for the oolites and the chalk. The mountains of Brittany, the chains of the Cevennes, the Jura, and the Vosges were also conspicuous in France, while the Black Forest, Odenwald, Harz, Erzgebirge, and Bohemian mountains generally had assumed their present relative heights. Also all the primary tracts of Britain, Scandinavia, Finland, and the Ural had long since circumscribed the ancient sea, or basin of Europe. But as yet the Pyrenees and Apennines, the Alps and Carpathians, had been only partially raised from the deep sea, though enough it would appear to divide the ocean into limited seas, gulfs, and bays, in which the tertiary strata were to be deposited.

This brief sketch will convey a tolerable notion of the observed extent of the tertiary deposits in Europe. The eastern and south-eastern parts of England, a large tract round Paris, another equally large area in the south-west of France, detached deposits in the Loire and the Allier, the valley of the Rhone, the valley of the Rhine from Basle to Mayence; the great hollow between the Jura and the Alps, the plains of the Danube and the Po, the subapennine region, many points in southern Spain, the central basin of Bohemia, these are the tracts at present best known, but they are not the most extensive. From the Ardennes, Harz, Riesengebirge, Carpathians, and Caucasus, great part of the space north-eastward to the

primary rocks of the Ural and Finland is composed of a variable mass of tertiary rocks resting on secondary and primary formations. The eastern coasts of North America, large areas in Northern Africa and in the region south of the Himalaya, are covered by tertiary rocks.

As far as appears at present, the marine parts of these deposits were formed beneath waters, some of which were connected with the German Ocean, as the eastern parts of England, the northern parts of Germany, &c., others with the English Channel and the Atlantic Ocean, as the south of England, Paris, Bourdeaux, and the remainder branched off from the Mediterranean, the Black Sea, the Sea of Azof, the Caspian, &c.

As in the present day the molluscous productions of one sea are distinguishable from those of another, by differing according to latitude and local circumstances, according to the nature of the coasts, influx of rivers, and many other causes, so we may expect the case to have been formerly. This is found to be the fact. The tertiary strata have several common and characteristic features, but they show differences of great importance, both mineralogical and organic, which clearly indicate the difference of circumstances of their production.

In the following tabular view, an attempt is made to fill with British phenomena the interval between the age of the chalk and the present period, and thus to place in one succession, geological, prehistorical, and historical time. In all that relates to the older marine portions of the tertiaries, we are specially indebted to Prestwich; the late Professor Forbes corrected our notions in regard to the lacustrine groups; Charlesworth, Wood, and Lyell, have cleared the horizon of the crag; Trimmer, Smith, Morris, and almost all English geologists have contributed to the illustrations of those later glacial and postglacial deposits, on whose animal contents, Buckland, Cuvier, and Owen have bestowed such successful attention.*

PERIOD OF MAN IN BRITAIN.†		
	HISTORICAL PERIOD.	
	Coins, constructions of civilized man, with remains of domesticated animals, and races extinct in comparatively late periods.	Fens, marshes, and river deposits of Cambridgeshire, Lincolnshire, Yorkshire, Lancashire, and many parts of Britain and Ireland.
	PREHISTORICAL PERIOD.	
	Rude instruments, marks of uncivilized structures, earliest kinds of burials, remains of red deer, long-fronted ox, common ox.	Broad gravel beds, deposited in valleys by fresh water—as in the Upper Thames and Cherwell Valleys—lacustrine deposits, &c., the level of the land nearly as it is now.

* This *method* of classification is exemplified in my recent work, entitled "Rivers, Mountains, and Sea Coast of Yorkshire."

† Geologists should be careful to remember that man is of more recent date in the western than in the eastern part of the world.

PLEIOCENE.	POSTGLACIAL PERIOD. The red deer, long-fronted ox, the Irish elk, Urus priscus, hippopotamus, elephant; forests of modern trees.	Shell marls under peat and other lacustrine and marine deposits, with living species of shells and insects, *the level of the land somewhat variable*, but for a time higher than now.
	GLACIAL PERIOD. (Sea.) Marine shells of arctic type.	The northern drift of gravel, clay, sand, &c., and erratic blocks transported by floating ice, and urged by currents of the sea; *the land being much depressed in* northern zones.
	PREGLACIAL PERIOD. Forests of modern trees; Irish elk, elephant, hippopotamus, hyæna, Felis spelæa, cavern bear, &c.	Lacustrine and peaty deposits, local gravels, *under glacial detritus*, bone caverns; land higher than its present level.
	CRAG PERIOD. (Sea.) Cetacea, mastodon, rhinoceros, Felis lutra; shells numerous, of existing genera, frequently of existing species.	Littoral deposits on the shores of the German Ocean, when the land was at a somewhat lower level than now (mammalia plentiful). Coralline and shell deposits farther from shore.

DISCONTINUITY OF SUCCESSION HERE.

MEIOCENE STRATA WANTING IN BRITAIN.

EOCENE.	UPPER MARINO-LACUSTRINE PERIOD. Palæotherium, anoplotherium chæropotamus, &c.; shells of existing genera.	Fresh water and marine deposits of Hempstead and Bembridge in the Isle of Wight.
	LOWER MARINO-LACUSTRINE PERIOD. Shells of existing genera.	Fresh water and marine deposits of Headen Hill.
	BARTON PERIOD. Shells, numerous, mostly of existing genera, but not often of existing species.	Marine argillaceous and arenaceous deposits.
	BRACKLESHAM SERIES—	Arenaceous, argillaceous, and lignitic deposits.
	BOGNOR PERIOD. Shells, numerous, mostly of existing genera, rarely of existing species; land animals mostly of extinct genera—Coryphodon, hyracotherium, didelphys, macacus.	Marine argillaceous and arenaceous deposits; Septaria.
	THANET PERIOD. Shells, few, analogous to those above, distinct from the mesozoic shells below.	Marine and fluviatile deposits, lignite, pebbles, coloured clays and sands.

We must here observe that there is no case where the crag overlies the fresh water beds, they being found only in separate districts belonging to different basins of the tertiary area. Notwithstanding

the want of direct sections, comparisons with the tertiary strata of other districts warrant us in classing the crag as a more recent deposit than the lacustrine beds.

EOCENE DEPOSITS

consist of several principal groups which are in many cases very distinctly characterized, and always appear to indicate considerable difference in the state of the waters which produced them.

The *plastic clay* group consists, generally, of green, yellow, and white sands, with or without marine shells, layers of rolled flints, occasionally furnishing attachment to oysters, clays and marls of a yellowish or bluish colour with shells, and sometimes of many various tints, and then mostly devoid of shells. Beds of lignite also occur in the sands of this group.

The sections of the plastic clay group are usually considered to be very irregular and confused, and so, indeed, they are, and mark, upon the whole, a turbulent period and varying velocities of water.

Prestwich classes them in three groups, thus placed in descending order:—

Upper part (basement bed of the London clay) pebbly.

Middle part consisting of blue clay, or marl, with cerithia, and other shells, or mottled plastic clays, sometimes alternating with sands, with or without shells (Woolwich and Reading series).

Lower part containing green sands often associated with flints and pebbles, and occasionally full of oyster shells, sharks' teeth, &c. (Thanet sands.)

The following section of Loam Pit Hill, near Lewisham in Kent, by Dr. Buckland, will serve to convey a good notion of the general characters of the plastic clay and Thanet sands group near London, except that the quantity of rolled pebbles is smaller than usual:—

	London Clay above.	Feet.
Plastic clay group.	Striped sand, yellow, fine, and iron-shot	10
	Striped loam and plastic clay, containing a few pyritical casts of shells, and some thin leaves of carbonaceous matter	10
	Yellow sands	3
	Lead-coloured clay containing impressions of leaves	2
	Brownish clay containing cythereæ, estimated at	6
	Three thin beds of clay, of which the upper and lower contain cythereæ and the middle oysters	3
	Loam and sand, in its upper part cream-coloured, and containing nodules of friable marl, in its lower part sandy and iron-shot	4
Thanet sands.	Bed of ferruginous sand containing flint pebbles	12
	Coarse green sand, containing pebbles	5
	Ash-coloured sand, slightly micaceous, without pebbles or shells	35
	Green sand identical with the Reading oyster beds, containing green-coated chalk flints, but no organic remains	1
	Chalk with beds and nodules of black flint.	

The green sandy lower part of the group, with or without pebbles, oysters, and other shells, and sharks' teeth, appears to be nearly constant and very characteristic, being found at Sudbury, Reading, Woolwich, &c.; scarcely occurs in the Isle of Wight.

The blue shelly clays of the middle part are well developed and rich in fossils, about Woolwich and other parts of Kent; in the Isle of Wight mottled clays of greater thickness (100 feet and more) appear, and constitute nearly the whole deposit between the shelly London clay and the chalk. At Newhaven, they much resemble the Woolwich beds in their zoological contents, and contain Websterite.

The range of the middle or truly plastic clay group, appears to be greater than of those immediately above or below. Prestwich's elaborate sections trace it from Kent to the Isle of Wight. In the eastern part of this range a marine character prevails among the organic remains; in the middle part they have a fluviatile and estuary character, (*e.g.*, Woolwich,) and in the western part the strata are mostly unfossiliferous, (ostrea bellovacina, however, is found there.) The organic remains are enumerated by Prestwich.*

They consist of two bryozoa, five genera of foraminifera, seven species of entomostraca, two species of monomyaria, twenty-eight species of dimyaria, (no brachiopod,) one annelid, twenty-seven species of gasteropoda, four or more fishes, a chelonia, a coryphodon, and phalangal bone of a bird. In the western district are layers of leaves. Prestwich is of opinion that the 'Druid sandstone' called also 'greyweathers,' and 'Sarsen stone' which lies on the chalk hills of Wilts and Dorset, is an exceptional product of this series.

The London Clay

is a very simple argillaceous deposit, of considerable but variable thickness, usually from 300 to 400 feet about London, and reaching 480 feet in Sheppey. It thins from this point in all deviations, gradually, and still retains in the Isle of Wight, where it was till lately included in the plastic clay series, a thickness of 200 feet to 300 feet. It is usually of a lead-gray, or blue colour, but dull brown and red clays occur in it, perhaps most usually in the lower part. Green grains are often observable in it, a few sandy layers occur, and these, usually containing green sand, are indurated at Bognor and Selsea into a considerable rock. Septaria abound in it, and some imperfect laminæ of marly limestone have been noticed. It lies upon the plastic clay group over considerable tracts in Essex, Berks, Hertfordshire, Middlesex, Hampshire, Surrey and Kent, on the northern side of the Wealden ridge, borders the southern coast from

* Geol. Journal, vol. x., p. 117.

Worthing to Hordwell, and separates the lower coloured clays of the Isle of Wight from the Bracklesham sands and clays and Barton clays and fresh water deposits above. It is chiefly interesting for the number, beauty, and variety of its organic remains, of which the cliffs at Sheppey are rich repositories. Considerable quantities were also obtained in cutting for the Archway at Highgate. There appear to be as many as four zones of organic remains in this clay, in the eastern district. The contents of each were given by Prestwich, in the *Geol. Journal*, 1854.

Having been much exposed to watery action, which it could ill resist, it is often left in insulated hills, upon the substrata of sands and clays. Mineral springs, so common to blue clays, rise in considerable number from the London clay near the metropolis. The most remarkable are those of Epsom, famous for their sulphate of magnesia, Bagnige Wells, and Acton.

It yields little water to the well-sinker, but on being pierced to the sands below, or, as circumstances may require, to the chalk, great streams of water rush up, and may even overflow the surface if the chalk hills which gather and transmit the water be sufficiently elevated. This is the case about London, under which subterranean streams flow from the chalk of Surrey on one side, and that of Hertfordshire on the other.

The London clay possesses all the characters of a very quiet and continuous deposit, perhaps in deep water, yet not far from shore, since many vegetable seeds, wood, and other considerable remains of land and littoral productions occur in it, as wood, turtles, and crocodiles, but no pebbles nor coarse sands.

The temporary turbulence of the plastic clay period had wholly passed away, and only finer sediment in great quantities found its way to the sea. Shells of the most delicate and fragile forms are perfectly uninjured in this clay, except in the rare case of its being laminated.

Bagshot Sand and Bracklesham Beds.

The Bagshot sand was described by Warburton. Its place is above the London clay, on which it rests in the only districts in which as yet it has been much noticed. Bagshot Heath and Hampstead are the principal localities near London. Its fossils are few and imperfect, but are thought by Warburton to resemble some of those found in the upper marine formation of the Paris basin.

Prestwich has examined the characters and geographical range of this thick and variable group. In the Isle of Wight, it was long included in the plastic clay and sand group, the true London clay in the cliffs there being insufficiently valued. According to Webster's

measure, these beds, vertical at Alum Bay, are there 864 feet thick, the lower part consisting of yellow irony sands, and thin alternating clays are supposed to correspond with the lower Bagshot sands near London. The upper part, a mass of alternating sands, variously and brilliantly tinted red, orange, yellow, green, black, white, with some dark and light clays and layers of lignite, is the series of Bracklesham Bay. It is in Alum Bay poor in fossils, but elsewhere that is not the case; for in this group many species occur in Whitecliff Bay (Isle of Wight), at Southampton, and Bracklesham.

Barton Clay Group.

This body of uniform dark clay, with scattered green grains, is conspicuous in vertical strata at the north end of Alum Bay Cliff, and again in the steep beds at Whitecliff Bay. In its thickness of 250 feet, are many layers of shells which, running up the cliff in parallel lines, offer the most unequivocal proof of the upturning of the strata through an arc of 90°; to this group belong most of the shells of Hordwell Cliff.

Headen Hill Group.

Above the Barton clay we find in the Isle of Wight about 100 feet of white and yellow sand, without organic remains, in beds much less inclined than those already noticed. These Headen sands are the base of the well-known fresh water marls and limestones of Headen Hill. These fresh water beds are in two groups, "upper" and "lower," parted by 36 feet of layers of purple and green marls, full to admiration of estuary and marine shells, distinct from those of the subjacent tertiary clays. Among them are potamida, by myriads, natica, neritina, voluta, fusus, ancilla, cyclas, venus, cytheræa, ostrea, &c. The "lower fresh water" beds, 63 feet, including some sands below, of Headen hill, are formed in many layers of marly and sub-calcareous bands, containing Limnææ, planorbes, &c., with slight partings of an estuary character. The "upper fresh water" beds are on the whole more stony, and more calcareous than the lower series, the total thickness, including some clays at the top of the hill, is above 70 feet.

In several respects the section at the east end of the Isle of Wight is more satisfactory than that which the well-known and famous cliffs of Alum Bay have yielded. It has been somewhat misunderstood; but Forbes's latest researches * have satisfactorily shown the occurrence on White Cliff Bay, of an upper fresh water group,

* Geological Journal, 1853.

(that of Bembridge,) separated by 100 feet of other strata from the lower one of Headen hill. The latter is here more marly than at Alum Bay. The series of fresh water beds is even here not complete, there being a still higher group at Hempstead, between Newtown and Yarmouth. At Whitecliff Bay, the beds above the Headen fresh water group, called

St. Helen's Beds,

consist of a marine lacustrine series, 100 feet thick. Above the calcareous beds, about 30 feet deposited from fresh water and brackish water, and then the

Bembridge Beds,

80 feet thick, consisting of marls, sands, and limestones, partly marine or brackish, with an oyster bed and cerithia, but mostly of fresh water origin. The Binstead quarries belong to this group, and yield palæotheria and anoplotheria, with some land shells. Finally comes the uppermost group of the island, the

Hempstead Beds,

170 feet thick, consisting of fresh water and estuary marls, carbonaceous clays, and marine sands and clays. These are the latest of the tertiary strata in the south of England, and of very limited extent, being confined, as far as at present known, to a hill on the coast between Yarmouth and Newtown, and a tract inland, near Newport, called Parkhurst Forest. Professor Forbes regards the whole series as "Eocene," but the upper part may perhaps be comparable with strata, which on the continent receive the designation of "Meiocene."

Dislocation of the Isle of Wight.—For our knowledge of the fresh water tertiary strata of England, we are indebted to Webster. They exist only along the northern side of the Isle of Wight, and on the opposite coast of Hampshire. The chalk and older strata, with the plastic clay and sands, and the London and Barton clays of the Isle of Wight, they were subject to convulsive movements. At Headen Hill the fresh water strata seem at first sight to have been deposited horizontally after great disturbance. They were not really independent of that great movement: at White Cliff Bay they are obviously and greatly elevated by it. There one might at first suppose the still higher fresh water strata of Bembridge to have been deposited level after the disturbance; but that is not the case. The great convulsion of the Isle of Wight bears a date later than that of the highest strata there anywhere visible.

ORGANIC REMAINS.

PLANTS.

CRYPTOGAMIA.

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Lycopodites,	1	...	1	...

PHANEROGAMIA.

MONOCOTYLEDONEA.

Flabellaria,	1	...	...	1

POLYCOTYLEDONEA.

Callitrites,	4	...	4	...
Frenellites,	4	...	4	...
Solenostrobus,	5	...	5	...

DICOTYLEDONEA.

Amentaceæ,	1	...	1	...
Carpolithes,	3	...	1	2
Comptonia,	1	...	1	...
Cucumites,	1	...	1	...
Cupanoides,	8	...	8	...
Faboidea,	25	...	25	...
Hightea,	10	...	10	...
Lauraceæ,	1	...	1	...
Leguminosites,	18	...	18	...
Mimosites,	1	...	1	...
Nipadites,	12	...	12	...
Petrophylloides,	7	...	7	...
Tricarpellites,	7	...	7	...
Wetherellia,	1	...	1	...
Xulionosprionites,	2	...	2	...

FORAMINIFERA.

Alveolina,	1	...	1	...
Anomalina,	1	...	1	...
Biloculina,	1	...	1	...
Cristellaria,	2	2	...	...
Dentalina,	6	...	6	...
Frondicularia,	1	...	1	...
Globigerina,	1	...	1	...
Globulina,	2	1	1	...
Marginulina,	1	...	1	...
Nodosaria,	6	1	5	...

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Nummulites,	4	...	4	...
Operculina,	1	...	1	...
Polymorphina,	1	...	1	...
Quinqueloculina,	3	...	3	...
Robulina,	2	...	2	...
Rosalina,	2	1	1	...
Rotalina,	2	...	2	...
Textularia,	2	...	2	...
Triloculina,	1	...	1	...
Truncatulina,	1	...	1	...

ZOOPHYTA.

ALCYONARIA.

Graphularia,	1	...	1	...
Mopsea,	1	...	1	...
Websteria,	1	...	1	...

ZOANTHARIA.

Astrocœnia,	1	...	1	...
Balanophyllia,	1	...	1	...
Dasmia,	1	...	1	...
Dendrophyllia,	2	...	2	...
Diphelia,	1	...	1	...
Holaræa,	1	...	1	...
Litharæa,	1	...	1	...
Paracyathus,	3	...	3	...
Stylophora,	2	...	2	...
Turbinolia,	8	...	8	...

ECHINODERMATA.

ECHINOIDEA.

Cidaris,	1	...	1	...
Cœlopleurus,	1	...	1	...
Echinopsis,	1	...	1	...
Echinus,	1	...	1	...
Hemiaster,	3	...	3	...
Schizaster,	1	...	1	...
Spatangus,	1	...	1	...

ASTEROIDEA.

Astropecten,	3	...	3	...
Goniaster,	3	...	3	...
Ophiura,	1	...	1	...

CRINOIDEA.

Bourguetocrinus,	1	...	1	...
Cainocrinus,	1	...	1	...
Pentacrinus,	3	...	3	...

ANNELIDA.

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Ditrupa,	2	...	2	...
Serpula,	5	...	5	...
Vermicularia,	1	...	1	...
Vermilia,	1	...	1	...

CIRRIPEDIA.

Balanus,	1	...	1	...
Pollicipes,	2	...	2	...
Scalpellum,	1	...	1	...

CRUSTACEA.

BRACHYURA.

Xanthopsis,	4	...	4	...

MACRURA.

Archæocarabus,	1	...	1	...
Basintopus,	1	...	1	...
Hoploparia,	1	...	2	...

ENTOMOSTRACA.

Cythere,	1	...	1	...
Cytherella,	2	...	2	...

BRYOZOA.

Cellepora,	1	...	1	...
Eschara,	1	...	1	...
Flustra,	1	...	1	...
Idmonea,	1	...	1	...
Lunulites,	1	...	1	...

BRACHIOPODA.

Terebratula,	1	...	1	...
Terebratulina,	1	...	1	...

MONOMYARIA.

Anomia,	1	...	1	...
Avicula,	3	...	3	...
Lima,	2	...	2	...
Ostrea,	18	4	14	2
Pecten,	10	1	9	...
Pinna,	3	...	3	...
Spondylus,	1	...	1	...

DIMYARIA.

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Arca,	11	3	4	1
Astarte,	3	2	1	...
Cardita,	8	...	8	...
Cardium,	11	2	9	...
Chama,	...	...	2	...
Clavagella,	1	...	1	...
Corbula,	13	2	9	3
Crassatella,	4	...	4	...
Cryptodon,	2	...	2	...
Cucullæa,	1	1	...	...
Cyclas,	1	...	...	1
Cypricardia,	2	...	2	...
Cyprina,	3	1	2	...
Cyrena,	12	4	4	4
Cytherea,	17	3	13	1
Diplodonta,	1	...	1	...
Dreissena,	1	...	1	...
Gastrochæna,	3	...	3	...
Glycimeris,	1	...	1	...
Isocardia,	1	...	1	...
Leda,	3	1	1	1
Limopsis,	2	...	2	...
Lucina,	12	...	11	1
Mactra,	2	...	2	...
Modiola,	8	1	6	1
Mya,	1	...	1	...
Mytilus,	1	...	1	...
Neæra,	3	...	3	...
Nucula,	11	...	11	1
Panopæa,	5	1	3	1
Pectunculus,	6	1	5	...
Pholadomya,	5	2	3	...
Pholas,	2	...	2	...
Potamomya,	2	...	2	...
Psammobia,	3	1	2	...
Sanguinolaria,	2	...	2	...
Solecurtus,	1	...	1	...
Solen,	5	...	5	...
Syndesmya,	1	...	1	...
Tellina,	24	...	24	...
Teredina,	1	...	1	...
Teredo,	1	...	1	...
Thracia,	3	1	2	...
Unio,	2	...	1	1
Venus,	1	...	...	1

PTEROPODA.

GASTEROPODA.

Achatina,	1	...	...	1
Actæon,	4	...	4	...

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Adeorbis,	1	...	1	...
Ancillaria,	4	...	4	...
Ancylus,	2	...	1	1
Aporrhais,	1	...	1	...
Auricula,	1	1	...	...
Bifrontia,	5	...	5	...
Buccinum,	5	...	5	...
Bulimus,	2	...	1	2
Bulla,	12	...	12	...
Calyptræa,	2	1	2	...
Cancellaria,	6	...	6	...
Cassidaria,	5	...	5	...
Cerithium,	32	4	26	2
Chemnitzia,	1	...	1	...
Clausilia,	1	...	...	1
Conus,	9	...	9	...
Craspedopoma,	1	...	...	1
Crepidula,	1	...	1	...
Cuma,	1	...	1	...
Cyclostoma,	1	...	...	1
Cyclotus,	2	...	...	2
Cypræa,	9	...	9	...
Delphinula,	1	...	1	...
Dentalium,	6	...	6	...
Emarginula,	1	...	1	...
Eulima,	4	...	4	...
Fasciolaria,	3	...	3	...
Fissurella,	1	...	1	...
Fusus,	31	3	28	...
Helix,	9	1	1	7
Hipponyx,	2	...	2	...
Hydrobia,	5	2	2	1
Limnæa,	21	...	21	...
Littorina,	1	...	1	...
Marginella,	8	...	8	...
Melampus,	1	...	1	...
Melania,	9	1	6	3
Melanopsis,	6	1	2	3
Mitra,	7	...	7	...
Murex,	12	...	12	...
Nassa,	1	...	1	...
Natica,	23	1	22	...
Nematura,	1	...	1	...
Nerita,	3	...	3	...
Neritina,	4	2	...	2
Odostomia,	2	...	2	...
Oliva,	3	...	3	...
Ovula,	1	...	1	...
Paludina,	5	1	2	3
Parmophorus,	1	...	1	...
Pedipes,	1	...	1	...
Phorus,	2	...	2	...
Planorbis,	14	1	8	6
Pleurotoma,	31	...	31	...

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Potamidum,	8	...	8	...
Pseudoliva,	4	...	4	...
Pupa,	2	...	...	2
Pyramidella,	1	...	1	...
Pyrula,	4	...	4	...
Ringuicula,	3	...	3	...
Rostellaria,	5	...	5	...
Rotella,	1	...	1	...
Scalaria,	8	...	8	...
Sigaretus,	1	...	1	...
Solarium,	9	...	9	...
Strombus,	1	...	1	...
Succinea,	2	...	1	1
Terebellum,	2	...	2	...
Terebra,	1	...	1	...
Triton,	3	...	3	...
Trochus,	1	...	1	...
Turbo,	1	...	1	...
Turritella,	15	...	15	...
Typhis,	3	...	3	...
Voluta,	31	...	30	1
Volvaria,	1	...	1	...

CEPHALOPODA.

Belemnosis,	1	...	1	...
Beloptera,	2	...	2	...
Belosepia,	3	...	3	...
Nautilus,	6	...	6	...

PISCES.

PLACOIDEI.

Myliobatidæ.				
Myliobatis,	18	...	18	...
Actobatis,	6	...	6	...
Pristidæ.				
Pristis,	4	...	4	...
Lamnidæ.				
Carcharodon,	2	...	2	...
Lamna,	6	...	6	...
Nictitantes.				
Galeocerdo,	1	...	1	...
Glyphis,	1	...	1	...
Naisia,	1	...	1	...
Notidanidæ.				
Notidanus,	1	...	1	...
Chimæridæ.				
Psaliodus,	1	...	1	...
Edaphontidæ.				
Edaphodon,	3	...	3	...

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Elasmodus,	1	...	1	...
Squalidæ.				
Otodus,	3	...	3	...
Spinax,	1	...	1	...
GANOIDEI.				
Sturionidæ.				
Acipenser,	1	...	1	...
Salamandroidei.				
Lepidosteus,	2	1	...	1
Pycnodontidæ.				
Gyrodus,	1	...	1	...
Periodus,	1	...	1	...
Pycnodus,	1	...	1	...
Phyllodus,	6	...	6	...
Pisodus,	1	...	1	...
Gymnodontidæ.				
Teratichthys,	1	...	1	...
CYCLOIDEI.				
Lophiidæ.				
Loxostomus,	1	...	1	...
Blenniidæ.				
Liparus,	1	...	1	...
Scomberidæ.				
Acestrus,	1	...	1	...
Bothrosteus,	3	...	3	...
Coelocephalus,	1	...	1	...
Coelopoma,	2	...	2	...
Coelorhynchus,	3	...	3	...
Cybium,	1	...	1	...
Echenus,	1	...	1	...
Naupygus,	1	...	1	...
Phalacrus,	1	...	1	...
Phasganus,	1	...	1	...
Rhonchus,	1	...	1	...
Scombrinus,	1	...	1	...
Tetrapterus,	1	...	1	...
Gadidæ.				
Ampheristus,	1	...	1	...
Goniognathus,	2	...	2	...
Merlinus,	1	...	1	...
Rhinocephalus,	1	...	1	...
Schomberesocidæ.				
Hypsodon,	2	...	2	...
Labrophagus,	1	...	1	...
Platylæmus,	1	...	1	...
Sphyrænodus,	3	...	3	...

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Clupeidæ.				
Megalops,	1	...	1	...
Halecopsis,	1	...	1	...
Murænidæ.				
Rhynchorhinus,	1	...	1	...
Dubiæ, fam. Pachycephalus,	1	...	1	...
Rhypidolepis,	1	...	1	...
Glyptocephalus,	1	...	1	...
Gadopsis,	1	...	1	...
Characidæ.				
Brychætus,	1	...	1	...
Siluridæ.				
Silurus,	1	...	1	...

CTENOIDEI.

Percidæ.				
Brachygnathus,	1	...	1	...
Coeloperca,	1	...	1	...
Eurygnathus,	1	...	1	...
Myripristis,	1	...	1	...
Percostoma,	1	...	1	...
Podocephalus,	1	...	1	...
Synophrys,	1	...	1	...
Scienuridæ.				
Sciænurus,	2	...	2	...
Labroidæ.				
Auchenilabrus,	1	...	1	...
Theutyidæ.				
Calopomus,	1	...	1	...
Pomophractus,	1	...	1	...
Ptychocephalus,	1	...	1	...

REPTILIA.

Crocodilida.				
Alligator,	1	...	1	...
Crocodilus,	3	...	3	...
Gavialis,	1	...	1	...
Lacertida.				
Lacertæ,	1	...	1	...
Ophidida.				
Palæophis,	4	...	4	...
Paleryx,	2	...	2	...
Chelonida.				
Chelone,	13	...	13	...
Emys,	6	...	6	1

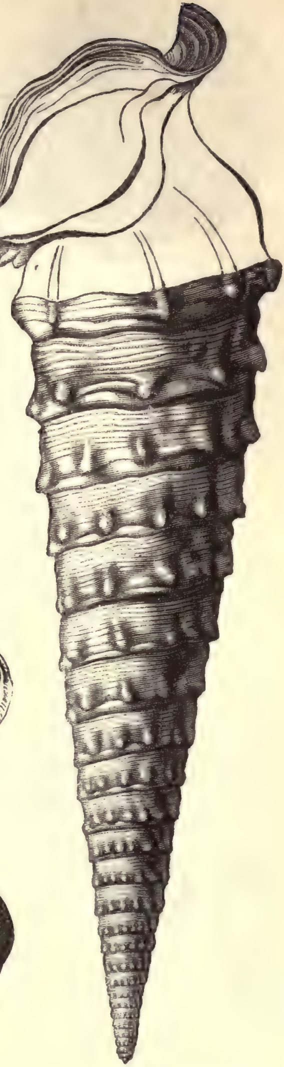
AVES.

	No. of Species.	L. Eocene.	M. Eocene.	U. Eocene.
Platemys,	2	...	2	...
Trionyx,	10	...	9	1
Halcyornis,	1	...	1	...
Lithornis,	1	...	1	...
Genus?	...	...	2	...
MAMMALIA.				
Pachydermata.				
Anoplotherium,	2	...	...	2
Chæropotamus,	1	...	...	1
Coryphodon,	2	...	2	...
Dichobune,	1	...	...	1
Dichodon,	1	...	1	...
Hyopotamus,	2	...	...	2
Hyracotherium,	2	...	2	...
Lophiodon,	1	...	1	...
Microchærus,	1	...	1	...
Palæotherium,	5	...	...	5
Paloplotherium,	1	...	...	1
CETACEA.				
Balæna,	1	...	1	...
MARSUPIALIA.				
Didelphys,	1	...	1	...
INSECTIVORA.				
Spalacodon,	1	...	1	...
CHEIROPTERA.				
Vespertilio,	1	...	1	...
QUADRUMANA.				
Macacus,	...	...	1	...

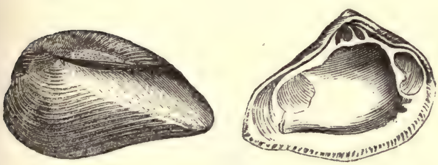
Note.—In the preceding lists, L. Eocene includes the Cainozoic strata below London clay; M. Eocene, the London clay, Bracklesham beds, Barton clay, and Headen beds; U. Eocene, the strata of Bembridge and Hempstead.

317

319



318



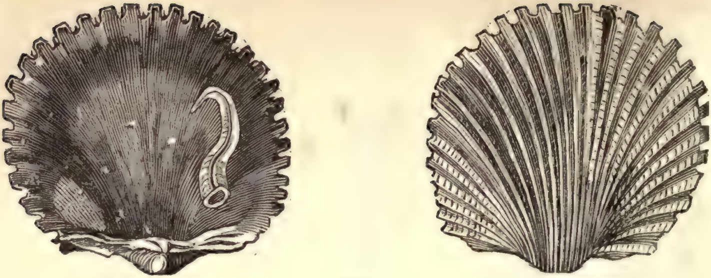
323

320

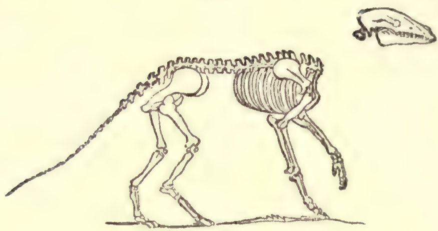
321

322

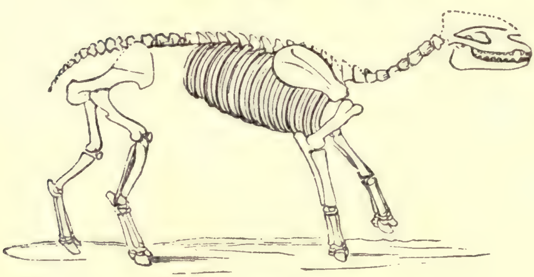
317 Nummulite in limestone.
318 Cerithium giganteum.
319 Turritella imbricataria.
320 Ampullaria acuta.
323 Crassatella sulcata.
321 Terebellum fusiforme.
322 Mitra scabra.



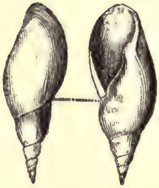
324



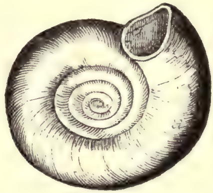
325



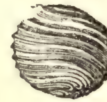
326



327



328



329

324 Cardium porulosum.
325 Skeleton of the common anoplotherium.
326 Skeleton of the great palæotherium.

327 Limnæa longiscata.
328 Planorbis euomphalus.
329 Chara medicaginula.

MEIOCENE STRATA

ARE BELIEVED NOT TO OCCUR IN THE BRITISH ISLES.

CHAPTER XIII.

PLEIOCENE STRATA.

Crag.

Range and Characters.—The most recent of all the marine stratified deposits, is also one of the most irregular. It occurs only in the eastern part of England over a narrow space of little elevation from the cliffs of Walton in Essex to beyond Aldborough in Suffolk. It is also known to some extent in Norfolk, particularly at Bramerton near Norwich, and has been found at Bridlington.

In this short course the crag is found to rest on the London clay at Walton and Bawdsey, and on chalk at Bramerton, being evidently a much later deposit than either, and wholly independent of them. It exhibits also considerable variation of character. Its general aspect in numerous pits in Suffolk is a ferruginous mass of shells, dark pebbles, and bones and teeth of fishes and reptiles, mixed up in a confused mass of sand, sometimes grouped into beds, and sometimes exhibiting oblique and disordered laminæ, very much resembling the general character of a modern very shelly beach. And from the manner in which it lies in the country about Ipswich and at Bramerton, there can be little doubt that it is really an ancient beach of the German Ocean. But about Aldborough and Orford the crag assumes a totally different character, becoming, in fact, a zoophytic limestone, an accretionary rock, formed by the cementation of coralline reliquiæ, shells, and calcareous sand, probably after the manner of the Guadaloupe accretionary limestone, and a similar littoral formation on the coast of the Isle of Ascension. This coralline limestone contains some of the most characteristic shells of the ordinary crag, and is clearly of the same era, or only one stage earlier than that heterogeneous deposit.

Charlesworth was led by his study of the crag deposits to consider them in three groups, thus placed and named:—

Upper group or Fluvio-marine Crag of the vicinity of Norwich, &c. Mammalia, littoral shells.

Middle group or Red Crag of Suffolk. Mammalia, reptiles, fish, and multitudes of invertebrata, often much waterworn.

Lower group or Coralline Crag of Suffolk. Few or no mammalia, abundance of invertebrata, not waterworn.

Shells of the Crag.—The quantity of shells contained in the ordinary red pebbly crag of Suffolk is beyond all calculation. The name of crag is, we believe, derived from a British word (cragen) signifying

shell, and the Suffolk pits have been for a long time in work solely to manure the ground with the calcareous exuviæ. Lately, taught by Henslow their value, the farmers have extracted from the lower part of the Red Crag abundance of bones, and coprolites, rich in phosphate of lime, and very valuable for manure. The bones are mostly rolled, and it has been supposed that some are derived from London clay—drifted, in fact, from that older deposit. The number of species here buried is also very great. Upon comparing them with recent kinds we are presented with very curious and striking results. There are several of the crag shells so exceedingly similar to recent shells of the German Ocean, that it is impossible to distinguish them. Turbo littoreus retains its colour, many others are with difficulty separated by minute discrimination; but some, as the corals of Orford, pecten princeps, terebratula Dalei, and others, are evidently unlike anything now existing in the German Ocean, and indeed not now to be paralleled in any part of the world. A small number of the crag shells appear very similar to some in the Eocene clay, but in general they have few common analogies, and the most cursory observer must be struck by the total difference of general aspect. The London clay shells recall to our memory the shores of a *tropical climate*, the crag fossils speak to us of an ancient race of shells more resembling those of *our own seas*. But the corals are *sui generis*, and upon the whole, those geologists who are most desirous of uniting the crag deposit to the present system of Nature, must acknowledge that it bears the stamp of an ancient and peculiar era. In Smith's work, (*Strata Identified*,) the tooth of a mastodon is figured from a noble specimen now, with this original collection, deposited in the British Museum, but without mention of locality. According to my recollection of what was stated to me by Smith, when his specimens were removed to the museum, and at other times, it was picked up under the diluvial cliff at Happisburgh, from which so many elephantoidal teeth and bones have fallen into the sea. The late Mr. Woodward (Syn. Table, 1830,) referred it to Whitlingham, near Newark, where such teeth in the same state of preservation have been found. And Mr. Woodward, now of the British Museum, states that Mr. Smith, in 1836, confirmed that reference. A very unexpected addition to the list of organic remains of the crag, is the badger, (probably undistinguishable from the common European species,) of which good specimens of the skull and leg bones are in the Yorkshire Museum. It may, however, be a case of later burrowing into the crag deposit. The bones usually dug at the base of the red crag belong to whales, mastodon, hippopotamus, deer, &c.

It must evidently be of little use to give sections of such a deposit as the ordinary crag. We shall therefore subjoin only Mr. R. Taylor's

account of the Bramerton pit, and mention that, in general its thickness is about 30 feet, and its greatest height above the sea, in Walton le Naze, 50 or 60 feet.

	Feet.
1. Sand without organic remains	5
2. Gravel	1
3. Loamy earth	4
4. Red ferruginous sand, containing occasionally hollow ochreous nodules	1½
5. Coarse white sand, with a vast number of *crag shells*	1½
6. Gravel with fragments of shells	1½
7. Brown sand, in which is a seam of minute fragments of shells 6 inches thick	15
8. Coarse white sand with *crag shells*, similar to No. 5, tellinæ and murices most abundant	3½
9. Red sand, without organic remains	15
10. Loamy earth, with large stones and *crag shells*	1
Total	49
Large irregular black flints crowded together *in situ* in the chalk. Attached to these flints are echini, terebratulæ, inocerami, and belemnites	1
Chalk to the bed of the river	15

ORGANIC REMAINS.

	No. of Species.
PLANTS.	
Nullipora,	1
FORAMINIFERA.	
Amphistegina,	1
Anomalina,	1
Biloculina,	5
Dentalina,	2
Glandulina,	1
Globigerina,	2
Globulina,	2
Guttulina,	5
Lagena,	3
Nodosaria,	1
Nonionina,	2
Operculina,	1
Planorbulina,	1
Polymorphina,	5
Polystomella,	2
Quinqueloculina,	6
Robulina,	2
Rotalina,	5
Spiroloculina,	2
Textularia,	4
Triloculina,	3
Truncatulina,	4

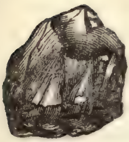
	No. of Species.
ZOOPHYTA.	
Alcyonium,	1
Flabellum,	1
Sphenotrochus,	1
ECHINOIDEA.	
Amphidetus,	1
Brissus,	1
Echinocyamus,	4
Echinus,	5
Spatangus,	1
Temnechinus,	4
ASTEROIDEA.	
Uraster,	1
CRINOIDEA.	
Comatula,	3
ANNELIDA.	
Cyclogyra,	1
Ditrupa,	2
Serpula,	1
Spirorbis,	3
Vermilia,	3
CIRRIPEDA.	
Acasta,	1

	No. of Species.
Balanus,	9
Coronula,	1
Pyrgoma,	1
Verruca,	1
CRUSTACEA.	
Atelecyclus,	1
Cancer,	1
Ebalia,	1
Fortunus,	1
Pagurus,	1
BRYOZOA.	
Alecto,	1
Cellaria,	2
Cellepora,	5
Crisia,	2
Diastopora,	1
Discopora,	1
Eschara,	6
Fascicularia,	1
Filicella,	1
Flustra,	5
Hippothoa,	1
Hornera,	2
Lepralia,	9
Lunulites,	2
Melicertina,	1
Membranipora,	2
Retepora,	1
Theonoa,	1
Tubulipora,	8
BRACHIOPODA.	
Argiope,	1
Discina,	2
Rhynconella,	1
Terebratula,	1
Terebratulina,	1
MONOMYARIA.	
Anomia,	5
Avicula,	1
Lima,	6
Ostrea,	2
Pecten,	10
Pinna,	1
DIMYARIA.	
Arca,	4
Artemis,	2
Astarte,	20
Cardita,	6
Cardium,	11
Chama,	1

	No. of Species.
Cochleodesma,	2
Coralliophaga,	1
Corbula,	2
Cryptodon,	2
Cyamium,	1
Cyclas,	1
Cyprina,	2
Cyrena,	1
Cytherea,	3
Diplodonta,	3
Donax,	3
Erycinella,	1
Gastrochæna,	2
Glycimeris,	1
Isocardia,	1
Kellia,	9
Leda,	6
Lepton,	4
Limopsis,	2
Lucina,	4
Lucinopsis,	1
Lutraria,	2
Mactra,	7
Modiola,	9
Montacuta,	5
Mya,	4
Mytilus,	4
Neæra,	2
Nucinella,	1
Nucula,	5
Pandora,	1
Panopæa,	3
Pectunculus,	3
Petricola,	1
Pholadomya,	1
Pholas,	4
Psammobia,	2
Saxicava,	1
Scrobicularia,	1
Solecurtus,	3
Solen,	3
Sphenia,	1
Syndesmya,	2
Tapes,	4
Tellina,	10
Teredo,	1
Thetis,	1
Thracia,	5
Venerupis,	1
Venus,	6
Venericardia,	1
PTEROPODA.	
Cleodora,	1

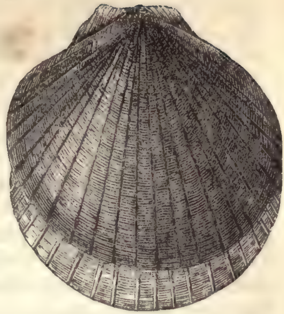
	No. of Species.
GASTEROPODA.	
Aclis,	1
Actæon,	4
Adeorbis,	5
Aporrhais,	1
Buccinum,	2
Bulla,	9
Calyptræa,	1
Cancellaria,	4
Capulus,	2
Cassidaria,	1
Cerithium,	8
Chemnitzia,	11
Columbella,	1
Conovulus,	2
Cypræa,	5
Dentalium,	3
Emarginula,	2
Erato,	2
Eulima,	3
Fissurella,	1
Fossarus,	1
Fusus,	12
Helix,	5
Hydrobia,	4
Limnæa,	3
Litiopa,	1
Littorina,	2
Margarita,	3
Marsenia,	1
Mitra,	1
Murex,	2
Nassa,	13
Natica,	11
Odostomia,	4
Ovula,	1
Paludina,	3
Patella,	4

	No. of Species.
Planorbis,	4
Pleurotomaria,	19
Purpura,	2
Pyramidella,	2
Pyrula,	1
Ringuicula,	1
Rissoa,	12
Scalaria,	13
Scissurella,	1
Sigaretus,	1
Succinea,	2
Terebra,	2
Trichotropis,	1
Triton,	1
Trochus,	17
Turritella,	7
Valvata,	1
Velutina,	3
Vermetus,	1
Voluta,	1
CEPHALOPODA—None mentioned.	
PISCES.	
Carcharodon,	1
REPTILIA?	
Otodus,	1
BIRDS?	
MAMMALIA.	
Mastodon,	1
Rhinoceros,	1
Asinus,	1
Felis,	1
Lutra,	1
Balænodon,	5

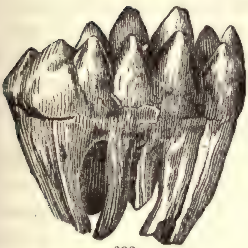


330

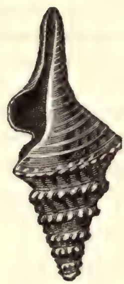
331



332

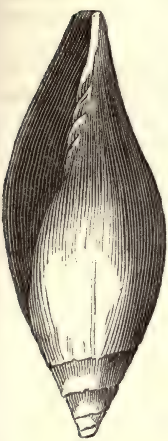


333



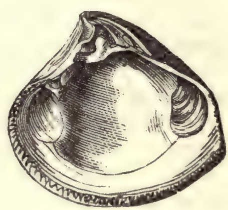
334

335



336

337



338

339

330 Balanus crassus.
331 Rosteliaria pes pelecani.
332 Pecten pleuronectes.
333 Teeth of Mastodon.
334 Pleurotoma rotata.
335 Buccinum prismaticum.
336 Voluta Lamberti.
337 Murex alveolatus.
338 Astarte Basteroti.
339 Cypræa coccinelloides.

CHAPTER XIV.

PLEISTOCENE DEPOSITS.

The uppermost group of the crag deposits, with its mastodon, rhinoceros, &c., may perhaps be nearly the fluvio-marine equivalent of the ferruginous gravel and irregular lacustrine deposits, *under glacial drift*, of the Happisburgh Cliff, or have immediately preceded it. In this deposit at Happisburgh lie bones of elephant and hippopotamus, ox, deer, and other animals, some of which also occur in the lower part of the glacial drift. A gravel deposit of corresponding age is found *under glacial drift* at Hessle, near Hull, and there yields bones of elephant, horse, ox. Probably to this date we may refer many of the most celebrated bone-caves, as those of Kirkdale and Kent's Hole in England, the bear caves of Gailenreuth, &c. In this period the old sea bed was enough *raised* to constitute dry land, probably continuous land, from Britain to the Continent.

Following this condition of things came a great depression of the northern zones in Europe and America. By this operation, the land sinking to form again the bed of the sea, we have acquired those great masses of "diluvial," or "detrital," or "glacial" clays and boulders which are so striking a part of the superficial deposits of Britain. This was succeeded by a farther elevation of the sea bed, whose effects are continued in part to this day.

Thus three main divisions of the pleistocene deposits of Britain come strongly into notice.—Preglacial land and fresh water deposits, glacial marine deposits, postglacial land and fresh water deposits. For the purpose of placing these phenomena in a steady light, we shall first treat of them in a district where the whole series is well represented, and continued to the modern epochs. Such a district is found in the eastern parts of England, as in Norfolk and Yorkshire. We take the latter tract for our type, according to the subjoined general scale :—

c Postglacial Period.—Peat deposits, lacustrine deposits, river deposits, sea beaches.

b Glacial Period.—Marine deposits, clay with irregular stones drifted from a distance, partially worn, or rolled pebbles, or erratic blocks, gravel beds, sand beds, shell beds interspersed.

a Preglacial Period.—Local drifts of gravel and sand, lacustrine marls, bone deposits in caves.

Preglacial deposits of gravel occur at Hessle, near Hull, and on the cliffs north of Bridlington, in each case resting upon the chalk. The gravel is composed of chalk and flint fragments, but

little worn; it is accumulated to the depth of a few feet or a few yards in thickness, sometimes aggregated into a sort of breccia. It seems to have been collected by local watery actions of no great violence, or of long duration, for the bones of quadrupeds which it contains are little or not at all water worn. These bones belong to elephant, a small species or variety of horse, ox, deer, and they have as yet only been found at Hessle.

At Bielbecks, near Market Weighton, the new red marl is excavated into little hollows, a few hundred yards in length; these hollows are partly filled with gravel, sands, and clays; the mode of aggregation varying from place to place. In one of these hollows the red marl was first covered by alternating argillaceous marls and local flint gravel, a few feet in thickness, without any organic remains. Over these lay about 12 feet of black marl, containing minute pebbles of chalk and a few small plants, and at the bottom two or three pieces of fine grained sandstone. In this marl were thirteen species of land and fresh water shells, viz., three land shells, Helex nemoralis, Helix caperata, Pupa marginata; *one swamp shell,* viz., Succinea amphibia; *nine fresh water shells,* viz., Limnæa limosa, Limnæa palustris, many specimens, Planorbis complanatus, many specimens, P. vortex, P. contortus, P. nitidus, P. spirorbis, Valvata cristata, Pisidium amnicum; with them occurred remains of Elephas primigenius, Rhinoceros tichorhinus, Bos urus, antiquus, large Cervus (probably C. megaceros), large horse. Felis spelæa, wolf, bones of a duck, an elytron of chrysomela, and a seed-vessel of some umbellate plant complete this catalogue of early terrestrial life. Above the black marl was found gray marl with *rolled pebbles* of quartz, mountain limestone, and sandstone of the carboniferous series, with chalk and flint 5½ feet thick. Here also occurred bones of elephant, horse, rhinoceros, and deer, but no shells or vegetable matter. Gravel and yellow sand, with chalk and flints, pebbles of quartz and sandstone, four feet and a-half thick, covered the whole, making a perfectly even surface, but sinking irregularly into the subjacent gray marl.*

The operations whose traces are thus disclosed appear to have begun with local action of water drifting materials from the foot of the neighbouring wolds of chalk and flint, which rest on blue clays. In a comparatively quiet period the nearer stratified deposits, (lias clays,) seem to have furnished the whole matter for the deposit, which, doubtless, was collected beneath the waters of a marshy pool, which nourished planorbes and limnææ, and received, by occasional currents, helices and succinæe from the adjacent plants. The gray marls above contain evidence of greater currents of water flow-

* Harcourt, Phil. Mag., 1830. Phillips's Geol. of Yorkshire, vol. i., p. 140. 1836.

ing from greater distances, bringing fragments from the western borders of Yorkshire, as well as others from the neighbouring hills; but the greater mass is still marly clay. The top is again the effect of local watery action. Nothing appears in any part of the excavation to indicate watery action, from *beyond* the drainage of what is near Yorkshire. Such gravelly deposits as those here described were covered in some neighbouring parts of Yorkshire by the ordinary boulder clay.*

A deposit of perhaps the same age as that of Bielbecks, was opened in the valley of the Aire, near Leeds,† in a sort of bay, of the old boundary of the valley. In the clay which here occurred, at a depth of nine feet, (20 feet above the river,) remains of hippopotamus major were found in admirable perfection; the tusks, teeth, cranium, examined by Mr. Denny, indicated several individuals. In this valley deposit, parts of Elephas primigenius, horse, stag, Bos primigenius, Bos latifrons, Cervus elaphus, and goat, have been found associated with hippopotamus. Trunks of trees, as oak, and fir, and hazel nuts, occur with them.

Whether we should refer to the same period the bones of hippopotamus and other animals found by Strickland, with 24 species of land and fresh water shells, in the valley of the Avon at Cropthorn, near Evesham;‡ the hippopotamus figured by Lee, from the marls of north Lancashire, under peat; the hippopotamus from the fresh water beds of Brentford, described by Trimmer,§ 1813; the elephant, beaver, and other mammals of Copford, recorded by Brown,‖ may be somewhat doubtful. It is remarkable how often the remains of the old river horse have been found in lacustrine and marsh deposits, and how nearly perfect his skeletons have been. In the case near Evesham, the bones were drifted, perhaps from still earlier lacustrine sediments, higher up the valley of the Avon. Two of the shells there found in fine sand under the bones are said to be of extinct species. At Copford, in the lowest bed of gray sandy gravel, occur 7 land and fresh water shells. Above this is a blue boulder clay, 11 feet thick, with fragments of stone, and many fossils derived from Yorkshire, Lincolnshire, and other localities. It contains 9 fresh water shells, and 3 entomostraca; and bones of elephant, urus, stag, bear, and beaver. On this blue clay is a layer of vegetable matter in a wedge-shaped mass, from 3 inches to 7 feet thick,—an argillaceous peat, containing Valvata piscinalis, and Cyclas rivicola, *in groups.* Over this a white shell marl, 1 to 6 feet thick, with 48 land shells, two of them (Helix incarnata, H. ruderata) of extinct species; and 22 swamp and fresh water shells. Here occur bones of ox, stag,

* Mr. Trimmer regards the deposit here described as of later (postglacial) date.—Geological Journal, 1851.

† Denny in Rep. Brit. Assoc., 1853.

‡ Geol. Proceedings, ii., 111.

§ Phil. Trans.

‖ Geol. Journal, 1852.

and elephant. Over all is a continuous widely spread reddish-brown clay, 1 to 6 feet thick, with chalk, flint, sandstone, limestone, conglomerate, and porphyry fragments—a tooth of horse occurred in it. In one locality this is covered by peat, with shells of recent species. Between the reddish-brown boulder clay above, and the reddish and gray gravel below, the shelly clays, peats, &c., are found in basins of limited extent, ancient lacustrine sediments. In the preglacial deposit at Happisburgh, already noticed, we have the further information of the condition of the surface, which fir trees rooted on the fluvio-marine crag, leaves, and seed vessels may give. The remains of elephant are here very numerous, and associated with bones of ox, deer, and horse. The deposit seems to have extended far to the east, many hundred molar teeth of the elephant having been dredged up by the fishermen from the oyster beds out at sea.

The deposits in Val d'Arno, which yield elephant and mastodon —the elephant supposed by Nesti to be of a different species (Elephas meridionalis) from that most usual in Europe (E. primigenius) may be of the same age as these preglacial accumulations of the Norfolk coast. The elephantine remains of Happisburgh have been sometimes referred to the Tuscan species or variety. The old lacustrine deposits on the east flank of the Ural which contains mammoth bones and gold, may belong to the same period, and doubtless many of the localities in Germany and France, which yield elephants' bones and land and fresh water shells, should be placed in the same part of the scale of geological time.

To the preglacial era belong, we think, the greater number of ossiferous caves and fissures, containing elephant, hippopotamus, hyæna, and other extinct species of animals. Those who desire to follow at length the detailed history of caves and osseous breccia must be referred to the luminous pages of Buckland (*Reliquiæ Diluvianæ*), and that imperishable monument of genius, the *Ossemens Fossiles* of Cuvier. We shall here present a simple analysis of the leading *results* of their inquiries bearing on the subject before us.

Caverns and fissures containing bones, however preserved, and of whatever kinds these are, present some important characters in common.

(1.) **Ossiferous Caverns, how situated.**—In the first place they are, we believe, always situated in limestone, very generally in stratified limestone, though this character is sometimes denied to the dolomitic limestone of the Mediterranean shores. This circumstance has, however, apparently no relation whatever to the accident of the caves containing bones, but is merely a general fact characteristic of limestone; for in this kind of rock nearly all the caverns, grottos, and remarkable natural fissures in the world are situated. And as far as we have observed, there is no reason whatever in speculations

on the *origin of the bone caverns and fissures* to exclude those of similar forms in which no bones occur.

(2.) This being the case, we may remark further, that though in some cases the existence of the cavern may be thought to be connected with dislocations of the strata, as at Greenhow Hill, in Yorkshire, yet this is rather the rare exception than the general rule. The carboniferous limestone is full of caverns, yet not more so where numerous slips and veins divide it than in other places. Veins of lead ore hardly ever lead to these caverns, and it is a matter of general remark, that though the strata may be disturbed near them, the disturbance has little to do with the caverns.

(3.) Most caverns, whatever be the character of their floor, assume at intervals along their length, the appearances of a great fissure in the rocks. This circumstance must have been often observed by those familiar with the caves of Somersetshire, Derbyshire, and Yorkshire, and is recognized even in that least favourable example, Kirkdale Cave, which in its nearly level course keeps its floor nearly on one particular bed of the rock, but occasionally opens upwards into narrow irregular expansions or fissures. The fissures filled with breccia may, in fact, be often regarded as exposed caves, and resemble them in all essential circumstances.

(4.) Very few of these cavities in the rocks are entirely free on their sides and roof from remarkable depressions and cavities, like those produced on limestone by currents of water, or the slow consuming agency of the atmosphere. Many of them which now convey water, and are not incrusted with stalagmite, as the Peak Cavern in Derbyshire, show this sort of watery erosion so strongly as to impress most beholders with a conviction that the whole was excavated by the running stream.

(5.) Several writers, in particular Brongniart, have attempted to show that mere water has no effect in eroding rocks. This may, perhaps, be true of the *oxyde of hydrogen*, but is certainly not a correct account of the effect of common water, and particularly of *water containing carbonic acid*, and traversing limestone rocks. The innumerable petrifying springs of limestone countries at once demonstrate the inaccuracy of this reasoning. The very rain from the heavens eats away these stones rapidly. The springs which issue from limestone generally contain carbonate of lime, and most of them yield a large quantity of free carbonic acid upon exposure to the air.

(6.) **How Formed.**—Those accustomed to underground works know it as a familiar fact, that the water which is absorbed by dry limestone land, takes particular channels through the rocks, down the joints, and along certain fissures. Every limestone hill in the carboniferous district of the north of England, shows in its *swallows* and *moor pits* the

erosive power of the atmospheric water. We shall, therefore, venture from all these considerations to maintain the enlargement or excavation of these caverns to be principally owing to the subterranean passage of water charged with carbonic acid, the direction of this water, and its power of erosion, being favoured by fissures and other causes. If the altered drainage and other circumstances of a country so far change the course of the water as to leave these subterranean channels almost dry, the small quantity of moisture continuing to arrive, may slowly deposit stalagmite over the surfaces formerly eroded, and the cave change its appearance altogether. An accidental inrush of water from another source may deposit mud or pebbles, and this be also covered up by another layer of stalagmite.

It is no great objection to this view, that the cavities are sometimes exceedingly irregular, for water in its subterranean course must follow the original cracks of the rocks. Indeed, upon a review of this matter, that very irregularity may perhaps be thought an argument in favour of the mode of origin here suggested.

The most remarkable ossiferous caverns in England are Kirkdale Cave near Kirkby Moorside in Yorkshire, the Dream cavern near Wirksworth in Derbyshire, Banwell Cave in the Mendip Hills, Kent's Hole near Torquay, Oreston near Plymouth, Cefn near Denbigh, and Paviland near Swansea; in Germany, the slopes of the Harz mountains give us the caves of Baumann, of Biel, and of Schwarzfeld. Between the Harz and Franconia is the Bear Cavern of Glucksbrunn; the Jura formation near Baireuth is celebrated for the rich associated caverns of Gailenreuth, Schœnestein, Brunnenstein, Holeberg, Wieserloch, Geissloch, Wunderhohle, Rabenstein, Kuhloch, Zahnloch, Schneiderloch, Rewig, &c. In Westphalia the same oolitic formation has the caves of Kluterhohle, and Sundwich. The Caves of Adelsberg in Carniola and the Dragons' Caves in Hungary have also yielded bones. In France, instructed by Dr. Buckland's researches, two caverns, rich with bones, have been described by M. Thirria near Vesoul, and several others near Montpellier and Narbonne by Marcel de Serres, Tournal, Christol, &c., and one near Miremont by M. de la Noue.

Osseous breccia appears singularly connected with the coasts of the Mediterranean. It occurs at Gibraltar, in Languedoc, and at several other points in the south of France, at Antibes, Nice, Pisa, Cape Palinurus, North of Bastia, (Corsica,) Cagliari, (Sardinia,) Maridolce, (Sicily,) in Dalmatia, Aragon, &c. Ferruginous breccia, in which bones are associated with pisolitic iron ore, occurs in Wurtemberg, and in Carniola, in Jura limestone.

How filled with Bones.—In some of these caves hyænas lived and dragged into them for food the bones of other animals existing in the vicinity; bears died in others; some were filled by the accidental

falling in of browsing quadrupeds, and others heaped with a mixture of bones, mud, and pebbles brought by general or local floods on the surface. We shall give an abstract of the characteristic facts attending each of these cases.

Kirkdale Cave is one of the most remarkable instances of ossiferous cavities known in England, both from the number of species and abundance of the bones of quadrupeds found there, their state of conservation, and other attendant circumstances. The entrance of this cave is on the side of a narrow valley 30 feet above the stream, in a nearly level and perfectly undisturbed bed of coralline oolite. It had a sort of vestibule, much larger than the interior windings of the cave, and in this, according to Salmond, lay a considerable proportion of the large bones of elephant, rhinoceros, &c. Beyond this was a STEP in the floor, of the thickness of one bed of limestone, leading to the interior recesses, which follow an irregular line, occasionally rising to the height of 14 feet, but generally under 4 feet, and about the same breadth, but liable to contractions in both their measures. The floor was generally overspread and its inequalities filled up by a layer of mud, of calcareo-argillaceous substance, such as might be supposed derivable from the joints and partings of the limestone. In some places the mud was more coarse and sandy. Stalagmite in considerable quantity had dripped from the roof, incrusted the sides, and covered like a sheet the layer of mud rising upon its surface into mammillary tubercles.

In the mud, and protruding occasionally through its stalagmitic covering, lay the bones of six or seven *carnivora*, hyæna, tiger, or lion, bear, wolf, fox, and weasel; three *pachydermata*, viz. elephant, rhinoceros, hippopotamus, the horse; four *ruminantia*, ox, and three kinds of deer; four *rodentia*, hare, rabbit, water rat, mouse; besides five birds, raven, pigeon, lark, duck, and a bird of the size of a thrush.

The bones were scattered over this long area, "as over a dog kennel," almost universally broken to pieces, not as if by common fracture, but by violent biting and gnawing: marks of teeth are discernible on many, exactly like those left by living hyænas on similar bones submitted to their jaws. Hyænas' teeth in great numbers, of all ages, milk teeth, shed teeth, and worn to stumps in the jaws of the animal, abounded in the cave, besides a considerable quantity of osseous fæcal matter, like that of the modern hyæna. From these data, most of which may be verified on the numerous specimens extracted from the cave, Dr. Buckland infers, that hyænas were for a long period the undisputed tenants of this den, lived in it for many generations, dragged into it for food, piecemeal, the bodies of animals then living in the neighbourhood, and were finally dispossessed of their hold by an irruption of water which let fall the muddy sediment now enveloping the bones. The ordinary action of

the water passing through the calcareous rock then covered the whole with stalagmite, and closed up the bones from the destructive agency of moisture and air. This accounts for the conservation of their gelatine. Few conclusions of this precise nature appear better supported by the facts of the case, and when we reflect on the remarkable analogy, in almost all points concerning the state and conservation of the bones, of the cavern at Torquay called Kent's Hole, and contrast these particulars of the *hyæna dens* with those of the *ox caves* in Mendip, we shall feel a full conviction that Dr. Buckland's bold theory is a true interpretation of nature.

Cave of Kuhloch.—The caves of Franconia appeared to Dr. Buckland to have been tenanted by bears which died in the retired parts, and were there mixed more or less with sediment and pebbles brought by subsequent diluvial floods, and the whole covered over by a stalagmitic crust formed in the usual way. The cavern of Gailenreuth is perhaps the most magnificent example of this doctrine; but that at Kuhloch presents some peculiarities of a very interesting kind. "It is literally true that in this single cavern (the size and proportions of which are nearly equal to the interior of a large church) there are hundreds of cart-loads of black animal dust entirely covering the whole floor, to a depth which must average at least six feet, and which, if we multiply this depth by the length and breadth of the cavern, will be found to exceed 5,000 cubic feet. The whole of this mass has been again and again dug over in search of teeth and bones, which it still contains abundantly, though in broken fragments. The state of these is very different from that of the bones we find in any other caverns, being of a black or more properly speaking dark umber colour throughout, and many of them readily crumbling under the finger into a soft dark powder resembling mummy powder, and being of the same nature with the black earth in which they are embedded. The quantity of animal earth accumulated on this floor," continues Dr. Buckland, "is the most surprising and the only thing of the kind I ever witnessed; and many hundred, I may say thousand individuals must have contributed their remains to make up this appalling mass of death. It seems in great part to be derived from comminuted and pulverized bones; for the fleshy parts of animals produce by decomposition so small a quantity of permanent earthy residuum, that we must seek for the origin of this mass principally in decayed bones. The cave is so dry that the black earth lies in the state of loose powder and rises in dust under the feet. It also retains so large a proportion of its original animal matter that it is occasionally used by the peasants as an enriching manure for the adjacent meadows." This cave is entered by a lofty arch, above the river Erbach, expands within both in height and breadth, and terminates in two chambers closed at the end. No

fissures enter this cave; and it has no other exit than the entrance above named, except a very small passage to the same valley. These circumstances are considered by Dr. Buckland to explain the absence of diluvial accumulations in this cave. There is no appearance of either stalagmite or stalactite having ever existed in this cavern.

Mendip Caves.—Dr. Buckland's views concerning the ancient occupation of hyænas and bears of the caves of Kirkdale and Franconia derive much elucidation from the discoveries of other caverns in which the animal remains appear to have been accumulated in a different manner. We shall mention those of Hutton in the Mendip Hills, and of Oreston near Plymouth; the former disclosed by ochre works, the latter by quarrying for limestone. The ochre of Mendip Hills appears, in some cases, to be derived from the decomposed strata of the vicinity, and deposited in caves and fissures of the limestone, either by water continually passing downwards by filtration, or by some more transient and violent operation. In pursuing one of these mines of ochre near the village of Hutton, bones of many animals were discovered; and the circumstances were examined by the Rev. Mr. Catcott, from whose manuscript Conybeare has drawn up a clear account of this remarkable occurrence. The elevation of the ochre pit was 300 to 400 feet above the sea. "The ochre was pursued through fissures in the limestone, occasionally expanding into large cavernous chambers, their range being in a steep descent and almost perpendicular. In opening the pits the workmen, after removing 18 inches of vegetable mould and 4 feet of rubbly ochre, came to a fissure in the limestone rock, about 18 inches broad and 4 feet long. This was filled with good ochre, but contained no bones. It continued to the depth of 8 yards, and then opened into a cavern about 20 feet square and 4 high. The floor of this cave consisted of good ochre, strewed on the surface of which were multitudes of white bones, which were also found dispersed through the interior of the ochreous mass. In the centre of this chamber a large stalactite was suspended from the roof, and beneath a similar mass rose from the floor almost touching it. In one of the side walls was an opening about 3 feet square, which conducted, through a passage, 18 yards in length, to a second cavern, 10 yards in length and 5 in breadth, both the passage and cavern being filled with ochre and bones. Another passage, about 6 feet square, branched off laterally from this chamber about 4 yards below its entrance. This continued nearly on the same level for 18 yards. It was filled by *rubbly ochre, fragments of limestone, and lead ore confusedly mixed together; many large bones occurring in the mass*, among which four magnificent teeth of an elephant were found. In the second chamber, immediately beyond the entrance of the branch just described, there appeared a large deep opening, tending perpendicularly downwards, filled with

the same congeries of rubble, ochre, bones, &c. This was cleared to the depth of 5 yards. This point, being the deepest part of the workings, was estimated at about 36 yards beneath the surface of the hill." * The bones found in Hutton Hole belong to elephant, rhinoceros, ox, horse, deer, hyæna, bear, a nearly complete skeleton of a fox, hog, and some gnawing animal.

Oreston Caves.—Three deposits of bones at Oreston, near Plymouth, have been detected by Mr. Whidby during the removal of the entire mass of a hill of Devonian limestone for the construction of the Breakwater. The first deposit (1817) lay in a cavern 15 feet wide, 12 high, and 45 long, and about 4 feet above high-water mark. This cavern was filled with solid clay, in which teeth and bones of rhinoceros were embedded. The second discovery (1820) was of a smaller cavern, distant 120 yards from the former, 1 foot high, 18 wide, and 20 long, and 8 feet above high-water mark. But the greatest extent of subterranean cavities was exposed in 1822, by the intersection of apertures in the middle of the limestone, containing an immense deposit of bones and teeth embedded in clay. Dr. Buckland describes in a very graphic manner the irregular branching or insulated fissures and caverns which were at this time laid open in an artificial cliff 90 feet high, their various direction, loamy contents, and relation to similar cavities not containing bones in the neighbouring limestone cliffs. He remarks that the fissures and caverns are so connected, so often confluent and inosculating with each other, and so identical in their contents, that there appears to be no difference as to the time and manner in which they were filled. In many of those which are nearly vertical, the communication is obvious, but those which pass obliquely, and consequently seldom lie in the plane of the cliff, may *appear* to close upwards. In almost all the cavities there occurs a deposit of mud and sand, and angular fragments of limestone; these substances sometimes entirely fill up the lower chambers, and are lodged in various proportions on the shelves and ledges and in lateral hollows of the middle and upper regions. In one large vault it is sorted into laminæ; sometimes it is interspersed with extraneous fragments of quartz and clay slate; stalagmite sometimes invests it; in some few spots were balls of ironstone, and concretions of ochre formed in the clay; in others was a considerable quantity of manganese ore, sometimes in concentrically coated balls. The bones collected in the Oreston caverns and fissures belong to hyæna, tiger, wolf, fox, horse, ox, deer. The bones of the horse predominated; those of ox and deer were also abundant.

We may admit, without hesitation, that these caverns and fissures at Oreston were filled with this mingled mass of earthy, stony, bony,

* Reliq. Diluv.

and metallic matters, by aqueous action; and there seems no good reason to doubt that partly in this manner, and partly by the accidental falling of quadrupeds into open fissures of the limestone, many other caves in Somersetshire, Derbyshire, &c., have been stored with their animal remains.

Osseous Breccia of the Mediterranean.—From such cavernous fissures, filled with mingled fragmentary masses, as those of Oreston, there is hardly a step to the fissures or caves containing ossiferous breccia at so many points around the Mediterranean Sea. Almost every limestone rock, wherever its interior structure can be seen on the sea coast, in ravines, in mines, is found to be traversed by fissures and excavated in caverns: it was therefore to be expected that such should be exposed in abundance in the calcareous precipices of the northern shore of the Mediterranean. But it is very remarkable that they should be in those regions so generally productive of bones; that these should so generally be found in a reddish coloured loamy breccia, holding fragments of the neighbouring rock, helices, and other spoils of the land; and that no marine production whatever should be found mingled with the mass, though, as at Santo Ciro, near Palermo, (*Geological Proceedings*, 1833,) there be proofs of the marine submersion of the actual cave, before the introduction of the bony breccia. There is clearly no necessary relation between the existence of these ossiferous cavities and the proximity of the sea; in many cases their exposure may be owing to the waste of the coast, but in others it must be mainly ascribed to the convulsive elevation of the land at some ancient period. In all cases the production of caverns and fissures in the rocks is the work of causes acting during periods long anterior to those when the animal remains were introduced. Thousands of cavities have been produced in the rocks, and filled with mineral treasures, and buried beneath vast depths of consolidated strata, of very high antiquity; such of them as were by any causes exposed at the surface, have been filled with clay, or heaped with fragments of rock, and in the great majority of instances lined with calcareous spar, and in countries which were then inhabited by quadrupeds some have been partly filled by bones. The geological era, when the latter occurrence happened, is rendered definite only by a rigid anatomical examination of the bones; and by this Cuvier has taught us that we may confidently refer the great majority of the quadrupedal remains, whether found in gravel on the surface, in the mud, gravel, breccia, or stalagmite, or on the naked floor of subterranean caverns, to one zoological period. In general, the most abundant remains in the ossiferous breccia of the Mediterranean shores belong to the orders ruminantia and rodentia; bones of ursine, feline, and canine animals, as well as those of hippopotamus and elephant, are rare. This is exactly what should happen upon

the supposition that the bones in the fissures were derived chiefly from animals which fell into them, for these naturally should consist principally of herbivorous tribes. The presence of land shells, of fragments of the neighbouring rocks, the abundant interlacement of stalagmitical carbonate of lime, tends exactly to the same conclusion; and even the redness of the breccia of Gibraltar, Cette, &c., is probably owing to the ferruginous nature of the neighbouring rocks. The influence of local causes is thus clearly indicated, and in the opinion of Cuvier, these have operated through considerable periods, so that the bones and fragments of rocks fell successively into the cavity, and the calcareous cement was gradually accumulated. If, in addition, we suppose, with Dr. Buckland, that these same cavities have since undergone the action of moving water, which might drift in heaps the fragmented bones and stones, and mix with them loam and occasionally pebbles, all the phenomena seem naturally explained, and the theory of the ossiferous breccia becomes connected with that of the proper cavern deposits. For particulars respecting the ossiferous breccia of Gibraltar, Cette, Antibes, Nice, Pisa, Cape Palinurus, Corsica, Sardinia, Sicily, Dalmatia, Cerigo, Aragon, and the Veronese, we must refer to Cuvier's admirable *Ossemens Fossiles*, tom. iv.

Glacial Deposits.

We have now passed through a long history of the deposits formed on the beds of the ancient sea, in its depths, along its shores, and in its estuaries, and we have noticed its contemporaneous or alternating accumulations from the fresh waters which then flowed upon the earth. The tertiary system of strata, by showing us remarkable alternations of fresh water and marine deposits, appears to establish a connection between the ancient and the modern world, between the subaqueous and the elevated land.

The whole of that system presents us with strong analogies to the present order of things, in its races of animals and plants; and its fresh water deposits have often a clear relation to the present level of the continents, and on this account might be viewed as the oldest of the modern formations.

Yet upon closer inquiry it will be found that in many cases a very strong line of distinction is drawn between the tertiary formations and the accumulations from actual seas, rivers, and lakes, by the intervention of an irregular mass of deposits, evidently produced by inundations of extraordinary height and powerful action upon the face of the dried and inhabited earth. These deposits are so extensive, and over large tracts of the earth's surface have so much of a common character, that they have very generally been classed

as the productions of one turbulent period in the process of the formation of the globe, and termed the diluvial deposits.

Origin and Use of the Term.—This term was first employed by Smith, and when subsequently adopted by the English School of Geology, it was often understood to refer to the effects of the Noachian deluge; and though on this point opinions are now more unsettled and various, the term may still be very properly employed by geologists of every school to mark the effects of turbulent inundations upon limited tracts of the inhabited land, happening within a particular period in the history of the globe. But its effects are not traceable universally; they are perhaps limited to the north circumpolar and temperate zones; and thus the term cannot be used with advantage in the sense generally assigned to it.

Without entering upon the unprofitable history of the delusions in which geologists have involved themselves on the subject of the Noachian deluge, it will be proper to remark that all discussions of this nature are useful or injurious according as they are carried on independently of or in connection with theology. Burnet and Woodward, by mixing up false hypotheses with scriptural history, retarded the progress of geological science, and sanctioned a perverse and uncritical application of the Mosaic narrative to support every new, fanciful, and unsubstantial theory.

We must bear in mind that it does not follow that all deluges must be referred to the Noachian flood; certainly many turbulent waves have traversed parts of the globe before the creation of man; some local deluges have happened since the days of Noah. The turbulent waters of which we are now to trace the effects upon the surface of the earth, may be quite independent of the deluge of Scripture; we have no right to *assume* any connection between them; and it will be prudent, before entangling ourselves in fetters which it may be difficult to unclasp, to wait for a full investigation of the subject. Many curious questions of time and circumstance are involved in such a comparison, on which a prudent philosophy—especially Christian philosophy—will be slow to pronounce a decision.

There is nothing in geology less improbable than the occurrence of a period of violent watery action, for in the course of our survey of the stratified rocks, we perceived clearly that, during their production, long periods of regular and ordinary action have been frequently succeeded by temporary disturbance. The epochs of these disturbances relatively to other phenomena are precisely assignable. They differ in importance, and while some are so great and extensive as to afford means of classifying the strata over large surfaces of the globe, others seem to have happened locally and irregularly.

The present system of nature may be considered as one of the periods of regular action, and the effects now produced upon the land

and in the sea are of the same kind as those occasioned during the comparatively tranquil periods of older nature, because upon the whole the levels of sea and land are constant. But the deposits called diluvial are characteristic of a period of watery tumult and disturbance of the most extensive kind, and are to be associated mentally with other great epochs of disturbance which mark temporary convulsions in the ancient system of nature. This watery tumult differs, however, from all anterior deluges, by the circumstance that we are looking upon the land and reading there the traces left by violent waves, while those of ancient times are, for the most part, known to us only by the effects they produced in the sea.

Proofs.—We shall now present the proofs of such a system of turbulent waters having passed over large portions of the surface of the inhabited earth, since the formation of all or nearly all of the stratified rocks now visible above the ocean, and since the present continents were dried, elevated, and inhabited.

Detritus from the Cumbrian Mountains.—Without venturing to assert that every region of the earth's surface is covered by the water-moved ruins of rocks, and waste of distant mountains, in situations to which existing streams could not carry them, we may state that observations of this nature are general for all parts of the continent of Europe, and frequent in Northern America, countries which have been, better than any other, explored by geologists. In all these regions, great deposits of gravel, sand, and clay, containing in more or less abundance portions of all the known rocks and strata, lie spread over formations of every age, primary, secondary, and tertiary. There is no order in the arrangement of these heterogeneous materials, no constant series or succession of deposits, but the utmost confusion and irregularity. The materials lie sometimes in valleys, often on hills, crossing in their course both hills and valleys, and appearing to have little relation to the track of the existing streams, though sometimes evidently influenced by the great physical features of the districts. Though the subject of the direction of diluvial currents, with reference to local geography, has not been sufficiently attended to, even in England, we are able to bring forward some striking instances in support of the preceding statements. It is well known that the mountain group of Cumbria encloses remarkable kinds of granite, syenite, and other rocks, and that they are separated from the eastern parts of the island by a long unbroken range of carboniferous limestone stretching from the Tyne to the Aire. A considerable hollow everywhere divides these ranges; and in some parts, as in the vale of Eden, the hollow is from 1,000 to 2,000 feet, or more, below the summits on either hand. The lowest point in the whole line of carboniferous limestone, which offers itself directly to the west, is on Stainmoor, about 1,440 feet above the sea. Now,

by the force of the currents of water alluded to, blocks of the curious porphyritic granite of Shap Fells have been removed from their original sites, (1,500 feet above the sea,) swept over a ridge of limestone rocks about Orton, into the red sandstone vale of Eden, 500 feet above the sea, and from this deep and ancient vale lifted up the steeps of Stainmoor to the very summits of the pass. From thence they have been urged forward as from a new centre, and spread in a radiating manner over the south of Durham, and the whole extent of the vales of York and Cleveland, to the foot of the Hambleton hills and the Wolds. Against these great barriers, considerable quantities of the rocks of Cumberland, and likewise of the carboniferous system of Yorkshire, are collected, but a large portion of the debris has also travelled over and beyond parts of these high districts and reached the sea side, where many of the cliffs are covered by blocks swept from Cumberland and North-Western Yorkshire. In passing from Shap Fells to Holderness, the granitic boulders have been transported across two deep vales, and over two elevated ranges of hills. In passing over these hills, we clearly perceive that the blocks were wafted by the easiest ascents. This is remarkably the case at Stainmoor, not the lowest point in the long carboniferous summit, but the one which directly faced the mountains from which the blocks started, and the only one crossed by the diluvial boulders. It is therefore evident that at the period when these violent waters flowed over the north of England, the land had assumed its present general shape and altitude; it is also clear that the floods were influenced in their direction by the great physical features of the country, but that at particular points they were of height and volume enough to overcome these natural obstacles.

Besides the porphyritic granite of Shap, other remarkable rocks of the eastern part of the Cumbrian mountains have followed the same course. The hypersthenic and syenitic rocks of Carrock Fell, the brecciated and amygdaloidal slates of Grasmere, Ulswater, &c. may be often recognized in the same situations. Perhaps the most instructive of all examples derived from this country is that furnished by the red "brockram" of Kirkby Stephen. This member of the saliferous formation is easily known by its fragments of carboniferous limestone embedded in red sandstone, and its native site is in the depth of the vale of the Eden. From this deep repository it has been lifted by the diluvial currents over Stainmoor, and thence carried with the granites and other rocks of the Cumbrian group. The rocks in several parts of the Cumberland and Westmoreland mountains are scratched and grooved as by the passage of heavy bodies. This occurs on Windermere, about Kendal, and near Ulswater.

The currents to which these effects are ascribed, must have flowed from the north-west. From the western part of the Cumbrian group

of mountains, currents flowing nearly from north to south have carried the granite of Ravenglass and Muncaster along the low ground west of the carboniferous chain of Yorkshire and Lancashire to the vicinity of Manchester, and through a great part of Staffordshire; but this sort of granite has scarcely anywhere crossed the carboniferous chain, to spread down the valleys of the Aire, Dun, Derwent, or Dove.* In this case, as in the former, it is evident that the current was directed by the great physical features of the country, which were the same then as now. In the vicinity of Ingleborough and Penyghent, blocks of slaty rocks have been *lifted* and carried several miles to the tops of limestone hills, and sometimes 200 feet higher than any part of the ranges of the slate.†

From the Lickey Hill.—The quartz pebbles of the Lickey have been widely diffused over the plains of Warwickshire and Gloucestershire to the foot of the Cotswold hills, but on arriving at this barrier they are stopped, except at two low points, the summits of the valleys of the Cherwell and the Evenload. Down these valleys, and along their borders, the pebbles hold separate courses till the streams unite near Oxford, after which the general course of the valley of the Thames is the track of the diluvial deposits.

A tendency to be arranged in narrow, longitudinal spaces is sometimes observable in the diluvial accumulations. In Lincolnshire a long narrow ridge of diluvial chalk runs out in a south-westward direction by Faldingworth. In Yorkshire the lias boulders from Robin Hood's Bay keep nearly parallel to the present north and south line of coast, and extend into Norfolk and Suffolk; and the flinty gravel from the Wolds runs north and south from Pocklington to Cave. These observations will probably be much extended hereafter.

Scotland.—The valley of the Forth and Clyde is filled at intervals by abundant deposits of the glacial period, filled, as those of England are, with rock masses from the north and neighbouring parts. In several districts round Glasgow, in Lanark, Renfrew, and Dumbarton, marine shells have been found in the drift, under it, and above it, and the general character of this deposit is the same as in England, the drift shells also indicating arctic analogies.‡ Pecten islandicus, and Cyprina islandica are among the most common of these shells.

Ireland.—The central area of Ireland, comparatively depressed in level, is very full of detrital deposits of the glacial era. The eastern and western counties are equally marked by such deposits. South of Dublin they spread to the foot of the mountains, and yield marine shells; in Mayo and the country farther north, they lie in great abundance, and show clearly prevalent currents from the north, and

* Glacial deposits occur in the valleys of Aire, Calder, &c., but they may have been placed there by currents returning from the east.
† Phillips's Rivers and Mountains of Yorkshire.
‡ J. Smith, in Wernerian Trans. 1839.

yield examples of perched erratic blocks. On the flanks of the Mourne Mountains, on the shores of the Lakes of Killarney, and on the sloping steeps which margin the bays of Dublin and Killiney, scratched rocks indicate the movement of heavy masses over the subaqueous or subaerial surfaces.

Russia in Europe.—Murchison* assures us that, from the German Ocean and Hamburg on the west, to the White Sea on the east, a vast range of country, having a length of nearly 2,000 miles, and a width varying from 400 to 800 miles, is more or less covered by loose detritus, including erratic blocks of colossal size, the whole of which is derived from the Scandinavian chain. There is often to be traced a certain arrangement or method of definition in these accumulations; they commonly appear in long zones, separated from each other by large breadths of depressed space clear from blocks. The accumulations are remarkable on plateaux and high grounds, and specially abundant on the southern slopes, the northern sides being often clear of detritus, and exhibiting marks of having sustained watery pressure. The rocks under and in the vicinity of these deposits are often striated. On Lake Onega, at Salomenskikamen, striæ appear on the north side of a hill, on the hill top, and below the lake surface, but not on the south side. Angular blocks sometimes lie quite distinct from other boulders The detritus, speaking generally, does not follow the descent of the surface, or the course of streams; but keeps in nearly straight courses, as for 700 or 800 miles, from Russian Lapland to Noroneje and Putievil, south and south-east of the place from which they started. The Ural chain and immediate slopes are free from detritus of this order.

North America.—In examining the surface of the North American continent, over a breadth of longitude of 2,000 miles, namely, from Nova Scotia, through New England, New York, the Canadas, Ohio, Michigan, Illinois, and the region west of the Lakes, nearly to the Rocky Mountains, it is certain that the general direction in which the boulders have been carried is south-easterly. The greatest part of the force by which they have been transported, has been confined between a south and south-east direction. This appears both by the distribution of the masses, and the scratching and furrowing of the rocks, which are recorded in very many localities, and in very striking forms. Exceptions, indeed, occur—directions to the west of South, for instance on the St. Lawrence, in the western part of New York, New England, and Vermont, where furrows run S.W. or S.S.W. The boulders do not appear to radiate from particular mountain centres, but to have crossed the high ridges and deep valleys. The lines on which their dispersion is noted are approximately parallel,

* See Geological Survey of Russia, chap. xx., for the following and other data, and excellent general and special reasonings.

the boulders grow less and less in size as we recede from their points of origin, except that often the huge rocks are *perched* on rocky hills and mounds of drifted material. Boulders have been *lifted* from lower to higher ground, even to a thousand feet and more, as where the blocks of quartz and silurian rock lie on the highlands of New York and Jersey. Striations are remarked on slopes and hill tops, even to a height of 2,300 feet above the sea, as on Mount Everett, and other high points in the hilly region of Massachussets.* They sometimes follow the course of valleys.

From the Alps.—The most extraordinary effects of tumultuous waters upon the surface of the land, appear sometimes to surround lofty ranges and groups of mountains. Thus the Mont Blanc group of primary mountains has been rent to pieces by some violent convulsion, and its mingled fragments transported along the *lines* rather than in the actual channels of the Rhone and the Arve into the Valais, along the Lake of Geneva, and up the slopes and through the valleys of the Jura even far into France. By this extraordinary course, blocks of enormous magnitude have been drifted in great numbers on to the tops of mountains, even to the height of 2,000 or 3,000 feet above the Lake of Geneva, and left there in such abundance as to encumber the land with thousands of extraneous masses. There appears in these collections of blocks a very singular tendency to association in groups and lines, (De Luc) and many striations and groovings on the rocks, under and near to the dispersed blocks, attest the force which accompanied the drift. It is particularly to be remarked that no ordinary action whatever could possibly cover the abrupt mountains of the Saleve and Mont Sion with such immense and numerous masses of these rocks, or transport them across the deep and wide valley of the Rhone to the steep slopes of the Jura. For such powerful effects it will be difficult to assign an adequate cause, and however much influence we may ascribe to the impetuosity even of an uplifted sea possibly co-operating with the disruption of glacier-covered mountains, the phenomenon must ever appear of the most remarkable kind.

We seem to perceive, on a general view of the dispersion of these *erratic blocks* from the Alps, a remarkable relation to the existing valleys. While the Mont Blanc group has yielded fragments to the Rhone and the Arve, the Bernese Oberland has supplied the basin of the Aar and the neighbouring part of the Jura; the valley of the Reuss has conveyed the waste of the mountains at its source; blocks from Glaris lie by the Lake of Zurich, and the valley of the Rhine holds the rocks of the Grisons.

The great range of the Jura, opposed to the Alps, and separated

* Hitchcock in Trans. Americ. Assoc. of Naturalists, p. 184; Rogers, Locke, Couthony, and other geologists, have expressed their views in the same valuable volumes.

from them by the long and wide valley of the Aar prolonged into the Lake of Geneva, has furnished the best opportunity of determining the geographical and other data belonging to the curious problem of the dispersion of these blocks. It is certain that in their course from the Alps the blocks have principally followed the line of the present valleys, since they are found along their sides in greatest plenty, and are collected in most abundance, and lie at the greatest heights, on those parts of the Jura chain which directly face the embouchures of the valleys. Yet this relation to the valleys is of such a kind, that the blocks, instead of being limited to their beds, lie perhaps more plentifully on the hill sides, and intimate a totally different kind of watery action from that of the running streams.

One of the grandest examples of the force and continuity of diluvial currents is the dispersion to the southward, across the Baltic, of the primary and transition rocks of Sweden and Norway. Brongniart (*Tableau des Terrains*) has given an excellent view of these phenomena.

From Scandinavia.—The sandy plains of Westphalia, Hanover, Holstein, Zealand, Mecklenburg, Brandenburg, the coasts and plains of Pomerania, Prussia, and part of Poland far inland between Warsaw and Grodno, and consequently all the low, generally flat and sandy countries which border the Baltic and German Ocean from the Ems and the Weser to the Dwina, and even the Neva, are covered at intervals by these blocks. They are not uniformly dispersed, but collected in particular spaces, and form in the midst of these vast sandy wastes distinct groups, generally elliptical in outline, with the longer axis directed north and south, or toward the Baltic Sea. Bruckner mentions a *trainée* of these blocks in the northern part of Mecklenburg-Strelitz, which runs from west north-west to east south-east. They are more abundant on hills than in valleys. The largest blocks are most superficial and nearest the tops of the hills. They consist of granites, syenites, silurian limestone with trilobites, &c., and other rocks which have the greatest resemblance to the rocks of Sweden; they contain the same *peculiar* minerals, and the same *peculiar* organic remains. Their course from the Scandinavian peninsula is generally from north-east to south-west. On approaching the mountains whence they were dislodged, we find the *number* of the blocks to increase considerably, and on crossing the Sound to Scania, they appear at every step, but the *size* of the blocks is not greater. The mountains of Sweden are not more burdened by loose blocks than is common to such tracts, but the faces of the rocks there appear furrowed and rubbed by the drifting of heavy bodies southward. The Baltic Sea, which crosses the line of these *trainées of rocks*, appears to have interposed no obstacle to their movement, since the heaps of blocks lie in the same direction on both sides of the water, and the quantities carried over are immense.

Some of the granitic boulders on the coasts of Yorkshire and Norfolk are thought to have come from the same Scandinavian mountains. From observations in England, Dr. Buckland inferred that the general direction of the diluvial currents was from the north-west. In North America, Dr. Bigsby and other observers have observed the prevalent direction to be from the north-west or north-east. The Scandinavian blocks have travelled over a tract widening to the southward. But the waste of the Alps has gone nearly as the valleys run, in all directions; southward to Italy, westward to France, northward to the Rhine, and generally we may be assured that the prevalent direction in any country has a very close relation to the physical geography of the region near the origin of the boulders.

The degree of attrition of the erratic blocks is various, and generally not so considerable as that of the smaller pebbles which compose the greater part of the diluvial masses. The great blocks are frequently found on the tops of the hills composed of gravel and clay.

Inferences.—From the preceding data we are warranted in concluding that since the deposition of all or nearly all the marine strata which are seen in our continents, and since the actual land was uplifted from the sea, and shaped into its present leading physical features, large parts of the earth's northern surface have been deluged by floods passing in various directions, which removed large quantities of the preconsolidated rocks, and dispersed them over distant countries, in such abundance, of such magnitude, to such distances, in such directions, and to such altitudes, as to preclude the possibility of explaining the phenomenon by the action of *actual streams*, flowing in the ordinary course of nature, or deviating in any possible manner over the surface of the earth, or by the bursting of lakes, however situated or circumstanced. For neither streams nor bursting lakes could possibly transport the Shap Fell granite to Flamborough Head, nor drive the syenites of Sweden into the heart of Poland.

Gravel Deposits.—For the sake of exhibiting decided proofs of the powerful action of the diluvial waters, we have insisted much on the transport of large blocks of recognizable rocks; but it must not be imagined that blocks of such magnitude compose the whole or the greater part of the diluvial deposits. These consist, in fact, of the detritus and fragments of every sort of rock, and of all sizes, from the giant blocks on the Jura to the finest sand and sediment. The eastern coasts of England, in Essex, Norfolk, and Yorkshire, are principally occupied by diluvial cliffs of clay, with interspersed pebbles and blocks, and irregular layers of gravel and sand. These deposits cover large tracts in Yorkshire, Lincolnshire, Norfolk, Suffolk, Essex, &c. In the Midland counties, gravel, containing in some places abundance of chalk flints, and in other situations pebbles from the Lickey Hill, is very common, and in particular valleys quantities

of oolitic gravel. It is generally observable that the most abundant portions of the deposits may be traced to the neighbouring ranges of hills, as the chalk of Holderness, Faldingworth, and Huntingdon, to the neighbouring wolds, the sandstones of the vale of York to the Western moorlands, and the quartz pebbles of Warwickshire to the Lickey Hill, but with them generally lie fragments from more distant sources.

In these gravelly deposits we not unfrequently find many marine shells, often littoral shells, and thus acquire a power of inferring the *least* depth at which the ocean stood upon the land. One of the best known cases is that brought forward by Trimmer, who, by examinations of Moel Tryfan, in North Wales, discovered littoral shells in drift about 1,500 feet above the actual sea level. This may be regarded as a fair general measure of the former elevation of the sea, or as all geologists now prefer to phrase it, the former depression of the land during the period of boulder dispersion. To this same height the distribution of blocks in Craven, and over Stainmoor in Yorkshire, and the parallel roads of Glen Roy, appear to conduct us. It is not necessary to suppose a greater, probably not so great a submersion for the lands in European Russia; but a greater depth is claimed for the depression in North America.

Theory.—In any attempt to connect the results by theoretical bonds, we must take into account several classes of phenomena which only long-continued attention has brought together in a form suited to the inductive philosophy.

1. The deposits are marine; they contain sea shells; they show in some parts local agitation such as belongs to shallow seas; in others, a confused aggregation, not to be so explained, and often are capped by blocks so vast as to defy explanation by any conceivable action of water.
2. The physical features of the country over which the detrital masses passed, were nearly as they are now; but large regions being submerged, it is clear that these physical features have had little effect in directing the main flow of currents, though some such influence can be traced on modifying the amount and arrangement of deposits.
3. The most general directions yet traced are from north to south, or from north-west to south-east—in which directions, seas as well as valleys have been crossed.
4. If watery forces may be *supposed* to be generated by violent convulsions, adequate to transport the huge blocks of rock, sometimes observed, these forces soon weakened by proceeding from their source, must further be supposed to be renewed from point to point, even when the slope of ground is favourable, and fail entirely, even with this help, to explain the drifting for hundreds of miles, across hills and valleys, and broad tracts of ocean.
5. For these cases, an obvious, and apparently adequate power, is recognized in modern icebergs, which, broken off from glaciers, at the edge of the sea, and bearing away whatever rocky materials may have fallen on those streams of ice, are delivered to the sea currents, and transported by them into lower latitudes and warmer climates, to melt, founder, or be overturned, and, in either case, to drop their far-travelled rocks and finer matters on the bed of a distant sea. Thus annually travel southward into the Atlantic the icebergs from the northern seas, and others northward from Victoria Land. In the former case, they melt

away, for the most part, in solitary masses, in the deeper parts of the Atlantic; in the latter example they congregate, in great numbers, along a zone of the sea 700 miles from their source, and there make a collected, and, probably, very large deposit, like the Osar of Norway, and Escars of Ireland. Such materials would be, in the main, a very confused mass; but yet, as the depth of the ocean varied, —at first shallow, then greatly deepened, and finally reduced to nothing as the land rose again,—the ordinary action of moving water must appear in them more or less. Shells appear in them, and it is curious to notice in these, among the drift masses of the northern zones, the only contemporary witnesses of the operations, a certain arctic character, suited to the probabilities of the case.

6. But, further, we find, on the most careful study, reason to think these icebergs, partially arrested in shallow water, and *dragging* on the sea bed, where that was covered with gravel, might so press on the rocks below, and so urge the grinding of them by the movement of the gravel, as to scratch, and groove, and polish them. This appeared probable to Lyell, and was confirmed by Murchison—after his study of Russia. Rogers and Hitchcock, after considering the worn limestones, gneiss, and other rocks of North America, and examining largely the whole subject, ascribe a great proportion of the drift phenomena to the same cause. Miller believes in the same agency for Scotland: it appears to us applicable to the phenomena over a great part of England and the borders of Wales.

7. Icebergs are not formed except at the edge of ice-covered land: they float away in masses of incredible size—even half, or two-thirds of a mile in length (*American Naturalist's Transactions*)—and sink into the sea 1,000, 1,500, or 2,000 feet! Tracing back the erratic blocks to their source—the track of the iceberg—we arrive at mountain summits like the Snowdonian range, the Cumbrian mountains, the Grampian range, the Alpine peaks, and the Scandinavian Fields. These tracts, then, were covered with glaciers down to the level of the sea, and, perhaps, to some considerable depth in it—as in Spitzbergen—the slowly, but perpetually descending streams of ice, carried on their surface, trainées of rocks, and at their extremity ploughed up the sea bed, leaving subaqueous moraines there, to be redistributed by the sea, according as the vertical movement of the land brought them under its influence. The sea round them was chilled by icebergs, drifting southward with return currents from the north; arctic shells appeared in the sea. Floating and melting, through enormous periods of time, the ice-rafts overturned, deposited, and sometimes mingled their spoils; and often dragged and agitated those of earlier date, and left them in forms to which no other explanation applies.

8. In order to account for the prevalent direction to the south, recognized in the boulder deposits and the structures of the rocks, we must suppose some considerable local displacements, or some general changes of level in the northern zones, by which the reciprocal currents from the equator and the arctic basin may have been turned quite into different channels from those which they now occupy. Such an hypothesis is required by the arctic shells in the old sea: it is equally required by the prevalence of glaciers on the northern lands; how these lands should be covered with glaciers, while, as the other phenomena prove, they were certainly at a lower level than now, and more completely bathed in the sea, is to be considered hereafter.

9. These inferences have their application from the Uralian chain to the Rocky Mountains, through half the circle of the 60th and 50th degree of latitude, and reach southward as far as the 40th. We must regard all this area, and probably large tracts beyond, as subject to the great vertical movements alluded to; it may not be necessary to suppose a strictly simultaneous depression of all that area, still less to regard it as a convulsive, sudden, or cataclysmal character, but it can only be viewed as one great operation, connected with one great physical cause, operating through one long geological period.

Postglacial Deposits.

Continuing our survey of Pleistocene deposits, we next behold the glacial sea bed uplifted, and the former relative levels of land and sea restored, or nearly so; for, in fact, many cases appear to show that the level of the land was somewhat more than regained. The cases of postglacial accumulations are to be considered chiefly with reference to the evidence they give of the state of the land: and this evidence consists in the remains of terrestrial animals and plants buried for the most part in lacustrine and fluviatile sediments. The marine postglacial phenomena are, obviously, for the most part, beyond our reach, covered by the waters of the actual ocean.

In the low district of Holderness, in East Yorkshire, the glacial sea bed is found elevated, and appears in ground about 160 feet, at a maximum, above the sea. The surface is very unequal, and exhibits a winding and complicated variety of levels, probably due, in parts, to the original irregularity of glacial deposits, but also to the action of waves upon them as they rose through the sea. In these hollows we find many lacustrine deposits—of limited extent, and of extremely various elevations above the sea. They are sometimes detected under the sea level, a fact on which probably we found the best evidence for the partial subsidence of land during the postglacial era. The lacustrine deposits alluded to, have frequently shell marl or a coarser clay as their bed; over this peat layers and the surface soil if any. There is sometimes more than one succession of the peat and marls. If all the varieties which I have observed at different places existed together, the sections would be nearly as under:—

7. Clay, generally of blue colour and fine texture.
6. Peat, with various roots and plants, and in large deposits, abundance of trees, nuts, horns of deer, bones of oxen, &c.
*5. Clay of different colours, with fresh water limnææ.
4. Peat as above.
3. Clay, with fresh water cyclades, and blue phosphate of iron.
*2. Shaly curled bituminous clay.
*1. Sandy coarse laminated clay, filling hollows in the diluvium.

The most constant beds appear to be 1, 2, and 5. The peat varies in thickness from five feet to a few inches. The most remarkable fossil animal in the marls under peat is the Irish elk. No case is known of elephant, hippopotamus, rhinoceros, felis, or hyæna in these deposits.

Lancashire, in the northern parts about Silverdale, Garstang, and other parts, discloses similar phenomena. Ireland produces them in abundance, the remains of the great elk being there almost ex-

clusively found in such deposits—the bones of this animal being commonly found in shell marl under peat, or partly in the marl and partly in the peat. The bones in peat are tanned brown. The Isle of Man, the Isle of Arran, and many other localities, give similar results, which it is unnecessary to particularize — since, by easy steps, they conduct us to the pre-historical and modern deposits of rivers and lakes, and are in fact only the earlier terms of the same series.

Organic Remains of the Pleistocene Period.

Animal Population at the time.—The land over which the glacial currents flowed was inhabited, and very extensively so, in many districts wasted by these floods. This is evident from the really immense quantity and variety of bones of quadrupeds lying in gravel pits, clay cliffs, and other diluvial accumulations, or buried in caverns during and previous to that period of convulsion.

To mention all the known localities for diluvial masses from which bones of elephant, rhinoceros, horse, ox, deer, and a variety of other quadrupeds have been obtained, would be to form a gazetteer of Europe, Siberia, and North America. There is hardly a county in England where some remains of this kind have not been obtained at many places, and they are equally abundant in France, Germany, Italy, Russia in Europe, North Asia, &c.

Exactly as at the present day the bed of a river envelops the shells that perish in the waters, with the bones of animals accidentally lodged there, so the pleistocene floods buried in the detritus of the land remains of the then existing organized creation. These remains enable us to say what races of animals were living upon the earth at and previous to the time when those parts of it were overwhelmed; and if upon examination it be found that these animals were of peculiar types of conformation, that they did not begin to exist till a certain epoch, nor continue to live after another epoch, the period of their existence is a *zoological era* as distinct as any other disclosed to us by examination into the long series of periods during which organic beings have existed upon the earth.

Inference.—In illustrating this magnificent subject from the materials furnished by the researches of Cuvier and Buckland, we shall first present the evidence furnished by diluvial gravel, clay, sand, and other unquestionable deposits of the turbulent era alluded to, and afterwards add some results deducible from examination of caverns, the period of the occupation of which will be naturally determined by comparing their zoological contents with those of gravel pits, &c.

The following are some of the mammalia that have been discovered in these diluvial and preglacial deposits :—

PACHYDERMATA.—Elephas primigenius, Mastodon augustidens, &c., Hippopotamus major, Chœropotamus, Rhinoceros tichorhinus, &c., Tapir giganteus, Sus fossilis.
SOLIPEDA.—Equus fossilis.
RUMINANTIA.—Cervus megaceros, &c., Bos, Urus, Mericotherium Sibericum.
CARNIVORA.—Felis spelæa, &c., Hyæna spelæa, &c., Wolf, Vulpes speluncarum, Machairodus cultridens, Ursus spelæus.
RODENTIA.—Porcupine, Beaver, Arvicola.
EDENTATA.—Megalonyx, Megatherium, two species, Manis giganteus.

Mostly congenerous with those now living.—The most striking general inference derivable from inspection of the preceding and more extended lists, as contrasted with all the catalogues of the earlier animals, is the almost complete identity of the genera with some of those which now exist. Even in the tertiary system, though the quadrupedal population of Europe had become considerable, and the circumstances of their existence in several respects closely analogous to what obtain at present, the genera were for the most part wholly different. Here they are for the most part the same.

The species, however, of the zoological era under consideration were mostly different from the existing races, some of greater magnitude, others of different proportions, all distinguishable by more or less remarkable peculiarities of their bony remains. These distinctions are often minute, and to those who estimate largely the amount of possible change induced on the animal frame by long time and varying circumstances, it may perhaps be conceded to preserve a slight doubt whether the distinctions alluded to be absolutely and always characteristic of the species of animals, or be modifications suited to the circumstances of their existence. However, for all the purposes of geological induction, the distinctions being constant are assumed to be specific, and in most cases we believe them to be so.

Among the species found in caves, fissures, and breccia, referred to the same era, are the following:—

PACHYDERMATA. — Elephas primigenius, &c., Hippopotamus major, Rhinoceros tichorhinus, &c., Chœropotamus, Sus fossilis.
SOLIPEDA.—Equus fossilis.
RUMINANTIA.—Cervus megaceros, &c., Bos, Urus, Antilope.
CARNIVORA.—Felis spelæa, &c., Hyæna spelæa, &c., Polecat, Weasel, Gulo spelæus, Wolf, Fox, Ursus spelæus, Ursus cultridens, &c.
RODENTIA.—Arvicola fossilis media, Arvicola fossilis minor, Rat, Lagomys, &c., Hare, Rabbit, &c., Beaver.

From the general analogy between these two lists, from the prevalence in each of elephants, rhinoceros, hippopotamus, felis, hyæna, and bears, in countries where at present not a single animal of such genera is known to exist, there seems very good reason to admit them as belonging to the same zoological era, which M. Omalius D'Halloy has, not inconveniently, called the mastozootic era. But all investigations concerning gravel and other diluvial deposits prove

indubitably that this era is exactly that which ended with the diluvial system of deposits. We may, therefore, venture in the following investigations to class together the remains of mammalia found in caves, fissures, breccia, gravel, clay, &c., as characteristic of a period of some duration, terminated in each district by great inundations, and equally capable of furnishing evidence concerning the then state of the earth. It is not meant by this arrangement to pronounce at all concerning the question, yet very insufficiently examined, of the partial contemporaneity of the palæotherian and mastozootic races of animals in Europe.

Lived in Countries where their Bones are found.—The first general result which we shall venture to draw from this combined evidence is, that the animals whose remains are found in diluvial gravel and other superficial accumulations, or in limestone caves and fissures, or in ferruginous breccia, lived near or on the spots where their bones are found. This important inference might be safely deduced from the ordinary circumstances under which fossil bones are found in superficial gravel, &c.; since in these cases they are little worn, though lying amongst fragments of rocks rounded to pebbles, and often remain entire, or with no other injury than that occasioned by the effects of the atmosphere. Thus the horns of a stag, scarcely in the smallest degree injured, have been obtained from the diluvium of the vale of Pickering, the long tusks of an elephant from that of Holderness and Essex. This conclusion might, perhaps, with equal certainty be rested upon the occasional finding of the bones of elephants and rhinoceros, and other "antediluvian" species, in marl pits under gravel, in company with shells now existing in the neighbourhood, of which some indications occur in Cuvier's celebrated work, the *Ossemens Fossiles*, and a more distinct case has been recorded at Market Weighton in Yorkshire. For in this case the bones of extinct and the shells of existing species of animals lay pellmell together, and the native locality of one must inevitably be ascribed to the other.

But the case becomes certainly stronger, when we take into view the history of the caverns, fissures, and breccia, containing bones; for these afford us not only reason to conclude that certain animals lived in definite regions at a particular era, but display many of their habits of life and accidents to which the nature of the country exposed them.

Climate of the Northern Regions in the Elephantoidal Era.—As no doubt whatever remains that in the "diluvial" period, and for a long time previous, there existed in Europe elephants, rhinoceros, hippopotamus, lions, and hyænas, besides bears, the glutton, wolves, foxes, the horse, oxen, the urus, deer, beavers, hares, rabbits, water-rats, &c., we are presented with a problem of considerable interest

relating to the state of the climate at that period. The most abundant, perhaps, and most generally diffused of all these remains are those of the elephant and rhinoceros; though in particular cases bears or hyænas fill whole caves, and the horse, ox, and urus are very plentiful in gravel and marl. So many animal remains of genera now exclusively confined to hot climates have induced many geologists to conclude that the northern regions of the globe were at that time much hotter, and that their total extinction was occasioned by a sudden refrigeration of the climate. On the other hand, the glutton, the urus, wolves, foxes, bears, horses, and large horned deer, and beavers, appear as characteristic of cold or temperate climates, and furnish arguments for the doctrine that the animals resembling those now living in tropical regions were fitted by some peculiarity of constitution to support the rigours of the northern zone. These statements are so equally balanced, and the authors who support them so respectable, that no impartial inquirer can pronounce between them without further evidence. This evidence must be of a particular kind. It will be of little use to add to the number of animals on either list; and as the *species* are *different* from those now in existence, the relative power of adaptation to climate of their several living analogues will not be sufficient to settle the point. We must find the remains of some of these animals in such condition, or accompanied by such collateral circumstances, as to characterize the climate independently of the generic relations of the animals.

Evidence on this subject.—Two cases coming within these conditions are known to geologists, of so distinct a kind, and leading so positively to the same conclusion, as to leave little room for further discussion. The first is the instance of an elephant, of the same species precisely as that usual in diluvial accumulations, being found in 1804, enclosed in solid ice, at the mouth of the Lena, where that Siberian river flows into the Arctic Sea. It was a perfect animal, with tusks in the jaws, and had evidently been entombed in its icy sepulchre immediately after death, for the flesh of its huge body was not decayed, but actually furnished a feast to the wolves and bears of the coast; the skin remained entire, and its whole surface was covered with *hair of two kinds*, one shorter and finer near the body, the other coarse and bristly, and even sixteen inches long. It is to be regretted that the difficult circumstances of the country did not permit Mr. Adams to examine minutely the anatomy of this specimen, thus wonderfully preserved through the fluctuations of ages; but the skeleton, mounted at St. Petersburg, furnishes sufficient characters to prove its perfect agreement with the fossil, and its distinctness from either of the living elephants. Here then is a plain proof that the fossil elephant was fitted, by an appropriate clothing, to withstand the occasional cold of a high northern latitude,

not perhaps to exist on the shores of the icy sea, but to inhabit about the sources of the Siberian rivers, and over the whole extent of Europe and a part of North America. The north coast of America, as well as that of Siberia, encloses abundance of the remains of these elephants in cliffs of frozen mud. (Captain Beechey.)

The conclusion from this fact is rendered still more decisive by the discovery, in 1770, of the fossil rhinoceros tichorhinus, under the same extraordinary circumstances of preservation of flesh, on the banks of the Wiluji, which falls into the Lena below Jakoutsk, and its body was likewise *covered with hair*.

Dr. Buckland's conclusion of some remarkable catastrophe and sudden refrigeration of the Siberian regions and the borders of North America, near Behring's Straits, seems to offer a reasonable explanation of the extraordinary preservation of these remains, which besides may have been drifted from their original seats northwards.

The second case is the discovery together in the same marl pit connected with gravel deposits, near Market Weighton, in Yorkshire, of the remains of elephant, rhinoceros, lion, wolf, horse, urus, ox, deer, &c., species all or nearly all extinct, with thirteen species of land, marsh, and fresh water shells now living in the neighbourhood. Now, as hardly any animals are more remarkably limited in climate, and restrained by local circumstances, than the molluscous tribes of the land and fresh waters, as the number of the species here discovered is considerable, and their identity altogether certain, without a single extraneous species, it is a safe conclusion, that the climate in which they lived was that which England and the central parts of Europe now enjoy; for such mollusca become mixed with other races on approaching the Mediterranean, and many of them cease to exist in the colder latitudes of northern Europe. The same conclusion results from the examination of that remarkable deposit called "Loess," in the valley of the Rhine, where the extinct elephants and rhinoceros lie with many existing land shells. (Horner.) Hence we conclude, with confidence, that the antediluvian climate of the northern parts of the globe was nearly the same that it is at present; and it is no great objection to this view, that the banks of the Frozen sea will not now feed an elephant, because, in the first place, it is not yet proved that the elephants were not drifted by the long Siberian rivers to their frozen mouths; and secondly, our conclusion is for a temperate or cold, not frigid climate, as distinguished from the torrid climate, to which some geologists would unmercifully subject these animals in their warm winter dress.

Geological Monuments of the Existence of Man.—In all the periods of time which elapsed during the formation of the stratified rocks, there is no evidence that man was a dweller on this globe. Not in the most recent of the eocene strata, neither in the littoral nor in

the lacustrine deposits of that period, have any traces of man or his works been perceived. This ought in no degree to surprise us, for all the animals and plants of that and earlier periods were *parts of an earlier system* of organized nature. But it appears something extraordinary that bones of men and vestiges of human art should have been so rarely found in any of the ascertained deposits of the diluvial era, except under dubious or explanatory circumstances, since at that time the earth had assumed its present form and appearance, and was inhabited by races of quadrupeds which, if not specifically the same, were, for the most part, closely analogous to those which now live; in particular, the horse and domestic cattle, animals so singularly serviceable to and dependent on man, existed in great plenty in the northern zones, and, therefore, the *present system* of organized nature, of which man is the head, may be said to have commenced.

That the bones of men are as durable as those of quadrupeds, is established by comparisons made on fields of battle, and, therefore, if he lived with the mastozootic quadrupeds, his remains should, under some circumstances or other, be found mixed with theirs. Dragged into a den by the prowling hyæna, or accidentally lost in a fissure, or overwhelmed by waves and buried in diluvium, we should occasionally meet with the bones of our ancestors. Old writers, who saw in everything only the traces of a general deluge, are full of discoveries of the bones of *men;* but modern anatomy has assigned them to their true analogies, the *elephant*, *salamander*, and *saurian*. In modern times a few examples of bones of men, found under circumstances arguing great antiquity, have been recorded. Upon strict examination it appears that in most cases these remains belong to a later epoch than the diluvial convulsions: the petrified bodies of the coast of Guadaloupe are enveloped in comparatively recent accretions; the human remains of the valley of the Elster, near Leipzig, appear to have been inhumed since the general dispersion of diluvium; the woman found in Paviland cave was of an early British era. The only cases remaining for further examination are some caves in the south of France, where the remains of man and rude pottery are found mixed with a quantity of bones belonging to extinct species of animals of the mastozootic era; superficial deposits in Baden and in Austria, where remains of men with depressed skulls (as if occasioned by unnatural bandages) are found; and the remarkable notices by Boué of mingled human and animal remains in the breccia of Nice and Dalmatia.

In South of France.—Without stopping to discuss the yet imperfect evidence concerning the antiquity of these remains in the breccia and superficial accumulations, we shall pass to the consideration of the caves in the south of France. From the examinations of Tournal, Christol, and Marcel de Serres, a considerable body of evidence

has been collected concerning the caverns of Bize, (Aude,) Durfort, Pondres, Souvignargues, (Gard,) and from the similar state of conservation as well as mixture of the bones of men and animals in the caverns of Bize, M. Tournal decides positively that their age is the same. These animals are stag, chamois, roebuck, antelope, and bear, which hardly require to be considered of the mastozootic era. The same conclusion was drawn by M. Christol, from subsequent researches in the caverns of Gard, in which the animal remains were decidedly of the same era as the fossil elephant and rhinoceros. But the most instructive, probably, of all these discoveries, is that of the cavern of Miallet, near Anduze, (Gard,) completely investigated by M. Teissier. This grotto, situated on the banks of the Gardon, is opened in a dolomitic rock subordinate to the lias, on a steep slope, thirty metres above the valley. The lower layer of the interior of the grotto is dolomitic sand, irregularly overspread by a thin stalagmitic crust, and in places by an argillo-ferruginous mud, more than a metre thick, and adhering in several places to the roof and sides. In this bed were discovered in great abundance, and excellent preservation, bones and teeth of large bears, and with them a few bones of hyæna, ruminantia, and birds; under the stalagmite, and under a bed of loamy sand from two to four decimetres, a great number of human remains was found in various parts of the grotto. In the depth of the cavern they are unquestionably mixed with the bones of bears, which predominate; towards the entrance, on the contrary, human remains are most abundant, and appear of less antiquity. Upon the ossiferous loam, under a little projection of rock, was discovered a human skeleton nearly entire, near it a lamp and small figure in earthenware; farther off bracelets of copper; in other situations coarse pottery, wrought bones, and edge tools of flint, indicative of ruder industry. The human skulls were depressed from above, apparently by artificial means, thus presenting a deceptive resemblance to the negro, though really belonging to the Caucasian race of men.

M. Teissier infers from these data that the accumulation of distinct periods can be traced in this cave:—1. The mastozootic or antediluvian era of the bears, with whose remains those of men are mixed, perhaps by subsequent natural or artificial means. 2. The era of rude civilization (probably Celtic,) when the coarse pottery, flint tools, &c. were introduced, perhaps, to grace the sepulture of individuals. 3. The era of Roman arts.

There is no necessity for hazarding a definite conclusion on the antiquity of these human remains, because there is very great probability of gathering much additional information by the discovery of new caves under different circumstances. In the meantime we may remark that the principal arguments for the coeval existence of men, and extinct pachydermata and carnivora in the south of France, is the

intimate mixture and equal conservation of the bones; and these arguments should not be slighted, for they would, probably, not have been resisted in any case of the mixture of quadrupedal remains. On the other hand, the known facts that parts of the Mediterranean shores were anciently possessed by Troglodytic nations, and that the custom of burying in caves, as well as retiring to them for safety, was very general in these countries, adds great force to the opinion of M. Desnoyers, that, in most cases, the human remains are of no greater antiquity than the early Celtic ages, in which similar works of art were executed. (See Desnoyers, *Rapport à la Soc. Geol. de la France*, 1831.)

It is clear that ossiferous caves have received their contents, some at one period, and some at another, and that in others operations of the same kind, repeated at very different periods, have consigned to our investigation monuments of all the great zoological changes which have happened on the dry land, since it first became tenanted by mammalia. The whole subject must yet receive a great accession of well-observed facts. One remark, concerning the excessive rarity or non-existence of human remains in diluvium, and in caves of the elephantoidal era, may be of considerable importance. Those parts of the earth's surface to which traditions and, perhaps, general reasoning, seem to point as the first sites of the human race, the central regions of Asia, have been as yet little examined with reference to this question. It may be very possible yet to discover them there even in abundance, though in the high northern regions men may not have existed till much later periods. It is a singular fact that the Quadrumana or monkey tribes, which so nearly approach to the bodily organization of man, are almost equally absent from the deposits of which we are speaking.

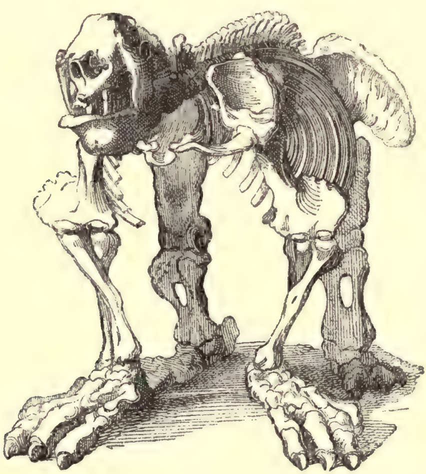
Upon the whole, the evidence yet obtained concerning *the geological period* when the human race began to exist on the globe, is very imperfect, and we may, perhaps, wait long for more full information. In the meantime, it may be stated as a general admission, that man did not exist on the globe during the secondary, and, probably, not during the epoch of eocene and pleiocene formations, and that sufficient evidence for his coexistence in Northern climes with the mammoths and hippopotami is yet wanting; but as the races of oxen, horses, camels, &c., had then begun to exist, it is not, perhaps, an unreasonable expectation that, eventually, this question will be decided in the affirmative.

GENERA OF PLEISTOCENE BRITISH FOSSILS.

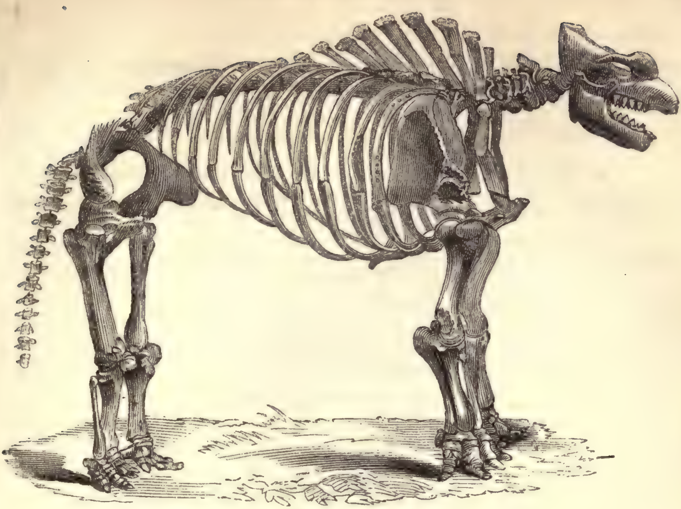
	No. of Species.
PLANTS.	
Filicites,	1
Chara,	2
Pinus,	2
Strobilites,	1
Taxoxylon,	1
Alnites,	1
Ceratophyllum,	1
Rhamnites,	3
AMORPHOZOA.	
Halichondria,	1
FORAMINIFERA.	
Rosalina,	1
ZOOPHYTA.	
Sertularia,	1
Balanophyllia,	1
Millepora,	1
ANNELIDA.	
Spirorbis,	2
CIRRIPEDIA.	
Balanus,	3
ENTOMOSTRACA.	
Bairdia,	1
Candona,	3
Cypris,	5
Cythere,	1
BRYOZOA.	
Tubulipora,	1
BRACHIOPODA.	
Discina,	1
MONOMYARIA.	
Anomia,	4
Ostrea,	1
Pecten,	3
DIMYARIA.	
Anodonta,	1
Arca,	1
Artemis,	1
Astarte,	5
Cardium,	3
Corbula,	1
Cyclas,	6
Cyprina,	1
Cyrena,	2
Lucina,	1

	No. of Species.
Mactra,	1
Modiola,	1
Mya,	1
Nucula,	1
Panopæa,	1
Pectunculus,	1
Pholas,	2
Saxicava,	1
Scrobicularia,	1
Solen,	3
Syndesmya,	1
Tellina,	4
Thracia,	1
Unio,	4
Venus,	5
GASTEROPODA.	
Achatina,	1
Auricula,	1
Ancylus,	2
Assiminia,	1
Azeca,	1
Balæa,	1
Buccinum,	2
Bulimus,	3
Bulla,	1
Carychium,	1
Cemoria,	1
Clausilia,	4
Cyclostoma,	1
Dentalium,	1
Fusus,	8
Helix,	24
Limax,	1
Limnæa,	5
Littorina,	2
Margarita,	1
Nassa,	3
Natica,	3
Paludina,	3
Patella,	3
Phasianella,	1
Physa,	2
Planorbis,	9
Pupa,	9
Rissoa,	7
Succinea,	3
Trochus,	1
Turritella,	1
Valvata,	3
Velutina,	2

	No. of Species.
BIRDS.	
Anas,	1
Alauda,	1
Columba,	1
Corvus,	1
Perdix,	1
MAMMALIA.	
PACHYDERMATA.	
Elephas,	1
Hippopotamus,	1
Rhinoceros,	2
Sus,	1
SOLIPEDIA.	
Equus,	2
Asinus,	1
RUMINANTIA.	
Urus,	2
Bos,	2
Capra,	1
Cervus,	5
Megaceros,	1
Strongyloceros,	1
RODENTIA.	
Arvicola,	3
Lagomys,	1
Lepus,	2
Urus,	1
Sorex,	3
Trogontherium,	1
CARNIVORA.	
Canis,	2
Felis,	4
Hyæna,	1
Machairodus,	2
Meles,	1
Putorius,	2
Ursus,	3
Vulpes,	1
CETACEA.	
Balæna,	1
Balænoptera,	1
Monodon,	1
Phocæna,	1
Physeter,	1
QUADRUMANA.	
Macacus,	1
INSECTIVORA.	
Paleospalax,	1
Talpa,	1
CHEIROPTERA.	
Rhinolophus,	1
Vespertilio,	1



340 Skeleton of Megatherium, Paraguay.



341 Skeleton of Mammoth.

342 Skeleton of the Irish Elk.

TABLE OF REMAINS OF MAMMALIA IN CAVERNS AND SUPERFICIAL DEPOSITS OF THE PLEISTOCENE PERIOD GENERALLY.

N.B. Extinct genera are marked with an asterisk. Caverns marked with *c.* Breccia with *b.*

Name.	In caverns and breccia of all ages.	In diluvial and earlier accumulations.
Remains of men	*c.* Gailenreuth, Zahnloch, Paviland, Bize, Durfort, Pondres, Souvignargues, Sicily	Köstritz, Rhine Valley, Austria, &c.
	b. Nice, Dalmatia.	
Vespertilio	*c.* Franconia, France	Köstritz.
	b. Cagliari, Antibes.	
Sorex	*c.* Avison.	
	b. Sardinia, Dalmatia	Ditto.
Talpa	*c.* Avison	Ditto.
Ursus spelæus, Blum.	*c.* Germany, France, England.. *b.* Krain, near Krembs, Munster	Chatillon.
arctoideus, Blum.	*c.* Franconia, Bize, Sallèles, Lunel Vieil.	
other species	*c.* Franconia, Sundwich, Fouzan, Sallèles.	
Machairodus cultridens, Cuv.	*c.* Sundwich, Kent's Hole	Val' d'Arno, Puy de Dome.
	b. Perpignan	Puy de Dome.
Nasua, Cuv.	*b.* Nice	
Meles vulgaris	*b.* Lunel Vieil, Sallèles.	
Gulo spelæus	*c.* Gailenreuth, Sundwich.	
Viverra, Clift	*c.* and *b.* Australia.	
Canis spelæus, (Wolf.)	*c.* Franconia, Bize, Sallèles, Kirkdale	Yorkshire.
	b. Sardinia.	
familiaris (dog)	*c.* Lunel Vieil.	
other species	*c.* Franconia, Bize, Sallèles	Val' d'Arno, Avaray.
Vulpes vulgaris?	*b.* Sardinia; *c.* Kirkdale	Perrierburg.
Hyæna spelæa, Goldf.	*c.* Kirkdale, Plymouth, Swansea, Paviland, Muggendorf, Harz, Fouvent, Sundwich, Lunel Vieil, Pondres, Kent's Hole, &c.	Köstritz, Canstadt, Eichstadt, Val' d'Arno, Herzburg, Abbeville, Lawford.
other species, Goldf.	*c.* Franconia, Sundwich, Lunel Vieil	Puy de Dome, Velay.
Felis spelæa, Goldf.	*c.* Kirkdale, Plymouth, Gailenreuth, Baumann's Höhle, Sundwich, Lunel Vieil	Köstritz, Val' d'Arno, Bielbecks in Yorkshire.
antiqua, Cuv.	*c.* Gailenreuth; *b.* Nice.	
other species		Upper Italy, Puy de Dome.
Mustela (polecat)	*c.* Lunel Vieil, Gailenreuth	
(weasel)	*c.* Kirkdale	
Lutra antiqua, M. de S...	*c.* Lunel Vieil	
other species		Puy de Dome.
Dasyurus, Hypsiprymnus.. Halmaturus Phascolomys, kangaroo, and wombat	*c.* Australia. (Clift.)	
Castor	*c.* Lunel Vieil	Val' d'Arno, Puy de Dome.
*Trogontherium Cuvierii, (Fisch.)		Taganrog, near the Sea of Azof.
Werneri, Cuv.		Jaroslav.
*Osteopora platycephala (Harlan)		Near the Delaware.
Mus	*c.* Kirkdale, Sallèles *b.* Gibraltar, Sardinia	Lawford.
Arvicola	*c.* Kirkdale, Gailenreuth, Sundwich, Gibraltar, Nice, Cette, Corsica, Sardinia.	
Hystrix		Val' d'Arno.
Lepus diluvianus and others	*c.* Kirkdale, Franconia, Sundwich *b.* Cette, Corsica, Nice	Puy de Dome.
Lagomys corsicanus, Brurdet	*d.* Sardinia, Gibraltar, Cette, Nice.	
Chloromys		Ditto.

Name.	In caverns and breccia of all ages.	In diluvial and earlier accumulations.
*Megatherium Cuvierii......	....	North and South America.
*Megalonyx Jeffersoni......	....	Ditto.
Dasypus, Bravard...........	....	Puy de Dome.
Elephas primigenius, Blum	c. Kirkdale, Warksworth, Mendip, Swansea, Muggendorf, Fouvent....................	Very generally in Europe, Asia, and North America.
meridionalis, Nesti......	....	Upper Italy, Puy de Dome.
several other species, according to Fischer	....	Russia, Podolia.
*Mastodon maximus, Cuv. ..	....	Very general in North America, Norfolk. (Smith.)
angustidens, Cuv.		
andium, Cuv.	....	Andes. (Humboldt.)
Humboldtii, Cuv.........	....	Chili.
elephantoides, Clift......	....	Irawadi in the Birman Empire.
latidens, Clift...........	....	Ditto.
arvernensis, C. and J....	....	Puy de Dome.
Hippopotamus major, Cuv. ..	....	In England very generally, Upper Italy, Puy de Dome.
undetermined...........	c. Palermo, Australia............	Irawadi.
Rhinoceros tichorhinus Cuv....................	c. Kirkdale, Warksworth, Plymouth, Swansea, Harz, Sundwich, Fouvent.............. b. Nice.	Siberia, England, Germany, France, Val' d'Arno.
leptorhinus.............	c. Lunel Vieil...................	Cussac.
minutus Cuv...........	c. Lunel Vieil, Pondres, Souvignargues.	
elatus, C. and J.........	....	Puy de Dome.
undetermined...........	....	St. Privat d'Allier.
*Elasmotherium Fischeri....	....	Siberia.
Equus, perhaps more than one species..............	c. Bize, Sallèles, Argou, Pondres, Lunel Vieil, Fouvent, Kirkdale, Mendip, Clifton, Plymouth, Swansea .... b. Nice, Antibes, Gibraltar, Dalmatia, Arragon..............	Köstritz, Brunswick, Canstadt, Val' d'Arno, Oxford, Essex, Yorkshire (frequent), Lawford, &c.
Sus.........................	c. Mendip, Bize, Franconia	Oxford, Val' d'Arno.
other species	c. Sundwich.....................	Puy de Dome.
*Chœropotamus.............	b. Villefranche-Lauraguais	Irawadi.
*Mericotherium Sibericum ..	....	Siberia.
Cervus megaceros, Hart.....	c. Kent's Hole.................	Very general in lacustrine deposits, probably less ancient than the diluvial deposits, England, France, Ireland.
tarandus priscus........	Breugue	Europe.
tarandus	....	Köstritz.
dama giganteus.........	....	Abbeville.
polignacus..............	....	Cussac.
elaphus.................	In English caverns generally....	Frequent in England.
Reboullii, Christol	c. Bize, Sallèles.	
several others...........	c. Ditto, ditto................... b. Gibraltar, Cette, Nice, Antibes, Pisa.	Cussac, Puy de Dome.
Antilope Christollii, M. de S..	c. Bize, Sallèles.	
other species............	b. Nice, Arragon................	Irawadi, Köstritz.
Ovis.........................	b. Villefranche-Lauraguais.	
Bos primigenius, Bojanus..	c. Salèlles, Bize, Lunel Vieil, Argou, Pondres, Souvignargues.	
bombifrons, Harl.........	....	Bigbone Lick, &c.
trochocerus, Von Meyer.	....	Upper Italy.
Pallasii, Dekay.........	....	Siberia, New Madrid.
Velaunus	....	Cussac.
undetermined...........	Kirkdale, Mendip, Plymouth, &c.	In various parts of England.
perus priscus, Boj	c. Bize, Souvignargues, Lunel Vieil, Pondres, Argou, Sallèles.......................	Siberia, North America? Yorkshire, and various parts of Europe.

We have not ventured to admit into the preceding list, the numerous remains found in the irony sands of Eppelsheim, which are stated to be related to the tertiary limestones of that vicinity, in

which also (see Meyer's *Palæologica*) bones of rhinoceros, &c. occur. These remains consist of species of gulo, felis, (not those of the caverns,) several small rodentia, cricetus vulgaris ? moschus antiquus, five species of cervus, (not those of the diluvium,) rhinoceros Schleiermacheri, (Kaup,) mastodon angustidens, m. arvernensis, three species of equus, tapirus priscus, lophiodon Goldfussi, sus antiquus, s. palæochærus, dinotherium giganteum, d. bavaricum, manis gigantea.

It may be remarked that in the valley of Rhine, and in some other parts of the continent of Europe, where local tertiary seas have left agitated deposits along their shores, and in the line of their currents, it requires extreme caution to apply with propriety the term diluvial. By an appeal to the organic exuviæ, where these are sufficiently plentiful, it may often be possible to resolve the doubt, especially where remains of the pachydermata are numerous. Thus elephants, hippopotami, rhinoceros tichorhinus, and certain bovine and cervine remains on the one hand, and, on the other, palæotheri, lophiodontum, &c. offer strong contrasts. But this test cannot always be applied, and it then becomes difficult to rely on the minute distinctions which probably almost always exist between the tertiary and diluvial species of the same genus. In this research much yet remains to be effected. Cases like those of Eppelsheim and Georgesgemund become in this point of view exceedingly important; for, by a comparison of many such instances, the series of zoological changes on the land, between the beginning of the tertiary and the end of the diluvial periods, may perhaps be eventually determined. At present we can only perceive that in general the palæotherian inhabitants of Europe had mostly ceased to exist in these limited districts before the elephantoidal races had spread themselves so widely over the northern zones; and can clearly show that the proportion of species belonging to extinct genera in the older tertiary deposits, was at least half, while in the preglacial deposits and caverns of the same date, it was about one-fifth. The remarkable extinct genus mastodon is common to the pleiocene and diluvial periods, and there may be reason to think that in some of the localities in North America, remains of these animals lie in postglacial lakes, like those which contain in Ireland and Yorkshire the bones of the cervus megaceros.

Dislocations of the Tertiary Strata.

After the deposit of the chalk and the plastic clay strata, and after the accumulation upon it of several regular marine and fresh water tertiary strata, extensive disturbances happened, by which the chalk and all the older strata were thrown into new positions, and the whole configuration of the land in the northern zones was greatly changed.

South of England.—In England, the effects of general convulsions at this epoch are very striking in the southern counties, and chiefly referable to two nearly parallel great undulations of the strata, of a peculiar character, ranging east and west. These undulations are of such a kind, that there are two imperfect axes of elevation and two parallel troughs. The northern trough is nearly in the line of the Thames from London to Reading, beyond which it appears to end; the southern trough is directed along the Solent, towards the extension of the chalk beyond Dorchester, beyond which it also appears to end. The northern line of steep dips passes through the Weald of Kent and Sussex, south of Guilford to Highclere in Hampshire, and is continued along the Vale of Pewsey, but ends towards Devizes. The southern ridge of strata passes through the Isles of Wight and Purbeck, and between Weymouth and Bridport, and ends at some point in the Channel before arriving at Torbay.

These great undulations appear evidently caused by violent elevation of the strata, affecting all the country between and beyond the two lines described; and it is exceedingly remarkable that the effect of the convulsion is such, that in each case the declination of the strata on the north side is generally very steep or *even vertical*, as at Guilford on the one ridge, and in the Isles of Wight and Purbeck on the other, while on the south side the chalk in Hampshire, and the green sand and oolitic groups in the Isles of Wight and Purbeck, are nearly level or slope gently to the south.

It is further observable, that for a certain length in the middle of each of these ridges the strata are vertical or nearly so, on the north side, but on each side of this length the inclination becomes less and less violent, and at considerable distances, in one of the ridges, is reduced to a gentle slope. Thus, on the northern ridge, the strata are violently inclined along the line by Highclere in Hampshire, (*where the chalk attains its greatest elevation in England,*) and at Guilford, but both westward toward Devizes, and eastward toward Kent, the slopes become gentle. Also on the southern ridge, the strata are *highly* inclined north of Weymouth, *nearly* vertical in the Isle of Purbeck, but *absolutely* vertical at the western end of the Isle of Wight, and in Culver cliffs (eastern end of the Isle of Wight) instead of being vertical are inclined 70° north. The broad elevation of the weald of Sussex, between these lines, is part of the same system.

From these data we may infer confidently that the disturbing force acted from below large regions, but was determined by local peculiarities and lines of weakness, particular lines, and most violently to certain points in these lines; and because of the unequal declinations of the strata on the opposite sides of the ridges, we may perhaps admit the force to have been exerted in *an oblique direction.* This

latter conclusion has often been suggested to us while considering the ordinary phenomena of *faults*.

Foreign Tertiary System.

Under what circumstances deposited.—The disturbances which preceded the deposit of the whole or the greater part of the tertiary strata, were very extensive, and appear to have operated considerable changes in the configuration of the land, and to have left the European seas, certainly expanded much beyond their present limits, but yet pretty evidently related to the present depths of the Atlantic, Baltic, and Mediterranean. It has long been the custom to speak of tertiary strata as being particularly deposited in *basins*; an inaccurate use of this term, for the tertiary strata are not more, nor perhaps so much, separated into basins as many of the older strata. We recognize, indeed, in them a greater local diversity, such as at present obtains, both with respect to the materials deposited and the organic remains entombed, in separate branches of the same sea, or at distant and dissimilar parts of the same coast. The true way of considering the tertiary strata is, to view them as the varied deposits of one long period, produced chiefly in branches of one great ocean, variously divided by the elevated lands. Some particular deposits may perhaps be best explained by allowing the existence of Mediterranean seas, or even salt water lakes. Cases in which fresh water and marine shells alternate must be examined upon their own evidence, to learn whether such alternations were produced in a lake, or at an estuary; and finally, the true fresh water strata of the tertiary period must be separately treated, having such relations to the marine tertiary accumulations as the fresh water formations of the present day have to the deposits now in progress below the sea. Thus we shall have purely marine strata, marino-fluviatile, or marino-lacustrine strata, and lacustrine strata all referable to the tertiary period, the relative eras of which can sometimes be correctly *determined*, sometimes satisfactorily *inferred*, and in other cases only *conjectured*.

The relative age of strata which were deposited in the same branch of the sea, can be *determined* by observation, even though subsequent convulsions may since have separated the deposit into detached portions, as for instance, the Hampshire and the London marine tertiaries. It can be *inferred* satisfactorily, even for originally distant deposits, when large suites of organic remains, not differing more than we may expect to happen in such cases, concur with a general analogy of geolgical position; and in this case, the inference is the stronger, if the data analyzed and referred in portions to successive periods, apply in a similar manner to the two localities.

The mineralogical character of the strata is of importance in

proportion as the deposits happened in the same branch of the sea, along the same line of coast, parallel to the same range of mountains, or to similar ranges of analogous rocks. In short, tertiary strata may be expected to show close agreement, considerable resemblance or general analogy, according to the local circumstances of their production, and it is perfectly consistent with geological experience and sound theory, that the clay of Barton Cliff, the calcaire grossier of Paris, and the lower subapennine marls, *may be* contemporaneous deposits, deriving their peculiar character from the peculiar circumstances of their localities. If we do not so often find in the older systems of strata these great mineralogical contrasts between exactly contemporaneous strata, we must remember that the circumstances of land and sea, when the earlier deposits happened, were more uniform, and that by a long succession of convulsions the tertiary sea was made to flow round islands and promontories, containing a vast variety of rocks, reared in deep or shallow waters, and exposed in various degrees to the process of disintegration.

We may venture by the aid of what is known of the effect of former convulsions, and the help of the characters furnished by the newer strata, to describe the hydrography of the great European sea in which tertiary strata were accumulated.

Extent of the Tertiary Sea of Europe, &c.—It may perhaps be described as an immense inland sea, bounded on the west by a broken line of elevated land in Spain, Auvergne, Brittany, England, Scotland; on the north by the Scandinavian peninsula, Finland; on the east by part of Russia, the Ural, the mountain circle which encloses the Aral, the Caspian, and the Black Sea, and a line prolonged through Syria toward the Red Sea; on the south by a line including the present Mediterranean, part of the Lybian Sands, and Egypt. This ancient Mediterranean appears to have been connected with the Bay of Biscay and the Atlantic by shallow channels between Angers and Poitiers, and by the line of the Canal of Languedoc. It embraced the North Sea, and so probably communicated with the Northern Ocean, included a part of the Baltic, and was open to the Indian Ocean through the Red Sea.

In this vast area rose at that time irregular tracts of land, forming upon the whole two islands. The northern island, stretching in a sweep from the Cevennes to the Carpathians, and including the great plateau of central France, the Jura, Vosges, Schwartzwald, Ardennes, Taunus, Westerwald, Teutoburger Wald, Harz, Erzgebirge, the circle of Bohemian and Moravian mountains, and the long range of the Carpathians. In the southern island rose in partial peaks, and with small surface, the Alps of that epoch, connecting themselves with the Apennines and the mountains of Dalmatia, Croatia, and Greece. The ancient sea of Bohemia and the sea of the Rheinland were

entirely or nearly surrounded by land; the seas of Switzerland and Hungary expanded into the Black Sea, and contracted their waters into a narrow channel along the line of the Rhone, there to unite with the Mediterranean; and the basin of Paris appears to have been only partially connected by shallow channels with the North Sea or the Bay of Biscay.

Its Relation to the Existing Seas.—Viewed, then, in connection with existing seas, we may consider the inland tertiary sea in several portions.

1. The arms and branches of the Mediterranean, stretching up the extended Gulf of Lyons, the Sea of Switzerland and Hungary and the extended Adriatic Gulf, washing the eastern part of Spain, Libya, and Egypt, and joining the Red Sea.
2. The dependencies of the Atlantic and North Sea, as the Bordeaux basin, which was also connected with the Mediterranean, the basin of Paris, the great Sea of England and the Netherlands. To these may be joined the area of Northern Germany, Russia, and the countries bordering on the Black Sea and the Caspian. We might perhaps be justified in making a separate division for the latter surfaces, could we appeal to any satisfactory account of the organic reliquiæ of countries which as yet are very imperfectly known.

For comparison with the English series, we shall first take the example afforded by the basin of Paris, so admirably described by Brongniart and Cuvier, and on that account frequently appealed to as the general type of tertiary formations.

Following the general classification of Brongniart and Cuvier, we shall divide the Parisian marino-lacustrine strata into five groups, in the order of their eras:—

5. Upper fresh water or epilimnic group.
4. Upper marine (sands and marls.)
3. Lower fresh water or palæotherian group.
2. Lower marine (calcaire grossier.)
1. Plastic clay group, subdivided by M. Brongniart into three parts.

Plastic Clay Group.—Our remarks on these deposits will be as concise as the great interest attached to a right understanding of the mode of their formation will allow. The idea we form to ourselves from a consideration of the plastic clay group of England, is that of a varied series of deposits, consequent upon some considerable convulsions, partly derived from the waste of the cretaceous system, and accumulated in a sort of estuary of that system. Pebbles and sands, with or without shells in confusion, a few bands of clay with shells, and beds of lignite, layers of pipe-clay, and plastic-clay, lying in sand, compose the rather heterogeneous group, which ends upwards with the abundant tranquil deposit of London clay.

On the great scale, the plastic clay group of the basin of Paris presents very analogous characters. It rests on the irregular and worn surface of the chalk, contains accumulations of pebbles, beds of

lignite, layers of coloured plastic clay, and by occasionally including beds of calcaire grossier, analogous to the shelly layers of the English group, appears to leave hardly any important point of resemblance unsatisfied. On a careful review, however, some differences arise. The order of succession of the several parts is not exactly similar. The French series taken generally may be thus expressed:—

Upper part consisting of potter's clay, marls, sands, and much lignite, the clay containing many lacustrine shells, as cyrenæ and melanopsides, alternating with a few marine shells, as ostreæ and cerithia; the lignites containing remains of mammalia and fresh water reptiles.
Middle part or plastic clay and sands, sometimes alternating, the former generally beneath, of very uncertain thickness, indistinctly stratified and devoid of shells.
Lower part very local, consisting of fragments of chalk, flints, &c.

These deposits are very unequally spread in the basin of Paris, and the lignite with shelly clays and marls belongs principally to the vicinity of Soissons. We may draw the following inferences. (1.) That the convulsive movements which wasted the chalk of England, and raised its originally deep strata to a littoral and estuary situation, were also experienced in the basin of Paris. (2.) That in this estuary irregular deposits happened, both marine and fresh water, the latter prevailing in particular places more than in the corresponding basins of England, and recognized by distinct layers of fluviatile mollusca, sometimes alternating with deposits containing a few marine shells. The basin of Paris seems therefore to have been at first an estuary, admitting into it considerable currents of fresh water from rivers or lakes, containing shells, crocodiles, and turtles, and transporting vegetables; but the deposits were generally more tranquil than the contemporaneous, or rather somewhat earlier, products of England.

The "*lower marine*" *group*, or calcaire grossier, and its coeval and associated sandstones, form the principal and characteristic rock of the Paris basin, in which the vast number of marine shells occur. The calcaire grossier is a granular, sedimentary, sandy, yellowish-white limestone of considerable thickness, regularly bedded and jointed, with partings of a marly nature, including occasional beds of sand, and in some cases lignite and marls. The lowest part of the rock is usually filled with green silicate of iron, and can hardly be distinguished from some kinds of marly green sand. It contains hardly the least trace of metallic substances, but encloses a few compact siliceous beds, some cubic fluor, quartz, and calcareous spar. It is the building stone of Paris. In some parts, it is replaced by a development of sandy beds, which often exhibit glistening fractures. Pebbles lie in it, chiefly at the top and the bottom. Upwards of 1,500 species of marine shells belong to this group, and only a very few land or fresh water species, rarely brought down with vegetables, diversify

the character of the deposit. A great proportion of the shells of the Barton clay are recognized among the more numerous reliquiæ of the Paris basin.

The lignite and marls occasionally included near the top of the calcaire grossier (Brongniart,) remind us that the action of the fresh waters, though nearly unobserved during this long period of depositions in quiet sea, might easily be recalled to the basin of Paris by a change of local circumstances.

Such a change occurring, a part of the basin of Paris was surrendered for a time to the undisputed possession of fresh water, and the following group was deposited.

Palæotherian, or Lower Fresh Water Group.—The palæotherian, or lower fresh water group, is principally, says M. Brongniart, a chemical deposit from water, or at least this mode of origin is very frequently to be traced in it. Coarse mechanical aggregates, the result of violent currents, are unknown in it; while gypsum, siliceous nodules, and agates are frequent, and sulphate of strontia, carbonate of lime, and silicate of magnesia occur in the marls which compose a large part of the mass of the formation. But it is from the remains of terrestrial and fresh water plants, and the exuviæ of land and fresh water animals, that this group of strata receives its most exact as well as most interesting characters. In the interior of its mass no marine bodies of any kind have been found, but several plants and shells of the land and fresh water, generically identical with existing tribes, as well as land quadrupeds belonging to genera now extinct. The study of these quadrupeds first awakened in Cuvier that indefatigable zeal in the examination of fossil animals, which has established the permanent union of the highest branches of geology and zoology.

Argillaceous and calcareous marls with limnææ, frequently alternating in very thin laminæ, (a common character of lacustrine deposits of all ages,) constitute the mass of this palæotherian group; gypsum in broad crystallized masses, of a vertically prismatic structure,* not stratified, is frequently associated with them, as in the basin of Paris, at Puy en Velay, and at Aix en Provence, siliceous limestone locally diversifies them, and yields agates, menilites, nectic quartz, &c. To this group M. Brongniart also refers the lignites which lie in the molasse of Switzerland. The quadrupedal reliquiæ are, perhaps exclusively, found in the gypsum, and few other organic bodies accompany them.

This evidently fresh water group occurs in many parts of France, sometimes, as in Auvergne and Cantal, without the least trace of a

* Mr. Chantrey, whose unrivalled eminence in his profession was united with very extensive and accurate information on other subjects, observed in the interior of plaster casts of large statues, which had been subjected to a drying heat of 350°, an irregularly prismatic structure, comparable to that of the gypsum of Montmartre.

genuine marine tertiary basis. About Montpellier it is found in combination with marine deposits nearly as in the Paris basin, and there appears good reason to believe that the causes which repelled the sea from that basin were extensively at work in other parts of Europe. This indeed is not a very difficult part of the problem. The expulsion of the sea may easily be imagined to have happened by the elevation of new land, or by a great local dislocation, such as we know to have often occurred; and thus a fresh water deposit in the basin of Paris might be laid on a basis of immediately antecedent marine tertiary strata, at the same epoch that in other parts of France elevated above the sea before the tertiary period, these deposits were laid on any of the older rocks. From the estuary or lake which we now call the basin of Paris, to the mountains of Auvergne, there might be formed, contemporaneously (that is, in a given geological period), many fresh water deposits of varying character, under varying conditions, which are to be ascertained by special investigation of each case. But after the completion of this lower fresh water deposit, subterranean movements brought back the sea into the basins of Paris and Montpellier, at the same time that marine exuviæ were introduced into the basin of Hampshire. It does not follow, as a necessary inference from the data before us, that this subterranean movement was centred below the basins of Paris, Montpellier, and Hampshire. It is only certain that subterranean movements must have occurred in such a manner as to interrupt and restore at intervals the connection of these districts with the ancient sea. In what respect is this different from the case of the Weald of Sussex and the ancient coal basin of Yorkshire?

Upper Marine Group.—The "*upper marine*" *group*, produced in the basin of Paris by the marine irruption which covered the palæotherian gypseous marls, is composed chiefly of sands of many colours, occasionally indurated to stone, with fewer shells than in the lower marine group. The base of the group is, at Montmartre, a mass of calcareo-argillaceous marls, greatly analogous to those of the fresh water group below, a gradation of character very much to be expected. Conglomerates lie on the coloured sands in the northern and eastern parts of the Paris basin. A sandy, shelly limestone, containing bones of the palæotherian, and also of the subsequent diluvian era, called *calcaire moellon* by M. de Serres, abounds at Montpellier and Narbonne. The molasse of Switzerland, a very complex and disturbed deposit, is referred to this era.

Upper Fresh Water and Epilimnic Groups.—The parallel between the three basins of Hampshire, Paris, and the south of France, is drawn still closer by the occurrence in all three of "upper fresh water" beds. It must in some cases be doubtful whether the upper fresh water deposit recognized in a tertiary district be of the anti-

quity of this Parisian epilimnic group, and it is highly probable that lacustrine deposits will be found of all intermediate ages from the date of the uppermost tertiaries of the Paris basin to the deposits of the modern era. Such, perhaps, are the lacustrine groups of Œningen and Georgesgemund, which have become better known to the English reader in consequence of Murchison's descriptions. But, in the case of the localities mentioned above, this doubt is not to be entertained. The most characteristic rock of this group in the basin of Paris is the millstone, a siliceous rock full of cells and tubular sinuosities, attributed to the extrication of gas from the bed of the lake, as is known to happen in ordinary cases, and some fresh water shells and seeds of chara. (Gyrogonites.) In other districts, especially in Italy, a marly limestone, analogous to the travertino which is daily formed there by carbonated springs, is considered by Brongniart the representative of this group, but it is obvious that this tufaceous deposit may be of all ages. The upper fresh water deposit, with, probably, other recent deposits of the same nature, is recognized in Auvergne and Cantal, on the Loire, Allier, and Cher, in the department of Gard, in Switzerland, Austria, and Hungary.

Faluns of Touraine.—To these characters of the strata in the Paris basin, described by MM. Brongniart and Cuvier, must be added a notice of a set of gravelly sands in the Faluns of Touraine, long celebrated for abundance of shells and other organic remains, but which were first examined with attention by M. J. Desnoyers. Along the line of the Loire valley at several points, as well as at Rennes, shelly and gravelly deposits occur, which, from Desnoyers' investigation, appear certainly to be of a posterior date to the whole Parisian formation, and to contain not only a variety of shells and corals distinct for the most part from those of the Parisian tertiaries, but also a mixture of quadrupedal remains, both of the palæotherian and mastozootic era. Besides palæotherium, lophiodon, and a species of anthracotherium, which would generally be referred to the era of lacustrine tertiaries, there are bones of mastodon, hippopotamus, rhinoceros, tapir, horse, and deer. These, the most recent, probably, of all the deposits connected with the Parisian series, were compared by M. Desnoyers with the English crag; but the propriety of this reference was denied by Lyell, on the ground that their suites of organic remains have not the same ratio of analogy to existing tribes. The Faluns are taken by this geologist as typical of Meiocene deposits. The affinity of the deposits of Touraine and Suffolk is, however, remarkable, and is admitted by D'Orbigny. Thus a sequence of tertiary deposits of the same general characters appears to be clearly ascertained in the southern parts of England and the northern parts of France, and the beds in the two localities indeed the same, or nearly the same geological period.

One of the last and most valuable contributions to geology by the lamented E. Forbes, is the following table, embodying a comparison of the Isle of Wight tertiaries, exclusive of the lower beds, with those of foreign localities.—*Geol. Journal, May*, 1853. The whole series is regarded as Eocene.

	Isle of Wight.	Paris Basin.	Belgium.	Mayence.	Vienna.	S.W. of France.	Mediterranean.
Hempstead Series.	Upper,............	.........0?.........	Rupelian or Upper Limburg,...	.........0?.........	.........0?.........	.... ?	Maltese beds, also Corsica, Greece, Crete, Cerigo, South of Spain, Portugal, Azores, North Africa.
	Middle,...........	Calc. lac. superieur, ...	Middle Limburg or Upper Tongrian, ...	Upper brown coal and cerith—kalk	Lower Viennese,..	Faluns jaunes of Dax, ...	
		Grès de Fontainebleau, ...	....	Marine beds,......	....	Molasse ossifere Calc. à astériees, ...	
	Lower,............	Marnes marines,..	Lower Limburg or Lower Tongrian,	....	....	....	
Bembridge Series.	Upper marls, ...	Gypsiferous marls and calc. lac. moyen,	.........0?.........	....	....	Molasse de Frousadais, and associated beds.	
	Oyster beds, ...		.........0?.........	....	....		
	Lower limestone,.		.........0?.........	....	....		
St. Helen's beds,..........		Gres de Beauchamp,........	....	....	....	.........0?.........	
Headen Series.	Upper,............						
	Middle,...........						
	Lower,............	Upper Calc. Grossier, ...					
Upper Bagshot beds,.....		Middle Calc. Grossier, ...	Lackenian, ...				
Barton beds,..............							
Bracklesham beds,........		Glauconie Grossier,.........	Bruxellian,.... ...	....	....	Calc. à Orbitolites.	

This agreement is very interesting. Yet it is not to be thought that in other parts of Europe, which have not been subjected to the same repeated convulsions, a similar sequence of marine with similar interpolations of lacustrine deposits should often be met with. On the contrary, it ought to be expected that when the tertiary deposits are wholly marine, the triple character, which in France and England they derive from definite periods of convulsion, should be confounded into a general series of many graduated or alternating terms, as happens to the oolitic and other extended marine systems. The further descriptions of tertiary strata, introduced for comparison with those of England, will be divided into marine and lacustrine; the former will be first noticed.

South of France.—The tertiary strata of the south of France are generally coeval with the upper groups of those of Paris, and the greatest assemblage of shells and other marine remains lies in sandy and subcalcareous beds, thought by M. Brongniart to be of the same age as the interlacustrine sands of Paris. In the districts of Bordeaux and Dax, 600 species of shells have been collected from these strata, which Lyell arranges in four divisions thus:—

4. Siliceous sand without shells.
3. Gravel.
2. Sand and marl with shells.
1. Blue marl with shells, sometimes 200 feet thick.

Below all these calcareous strata occur with shells of the Paris basin.

M. de Serres has shown the much greater accordance which the Bordeaux and Montpellier shells bear to those of the subapennine formation of Italy than to the strata of the basin of Paris, and it is from comparison of the organic remains that Lyell ranks together the Bordeaux and Touraine shells, and puts them above all the Parisian beds. It is desirable to attain an accordance of opinion in the relative age of these strata, because they furnish common ground of comparison for the deposits which border the Apennines, the Alps, and the Carpathians.

North of the Alps.—The most complete section of tertiary strata along the Alps has been furnished by the researches of Murchison and Sedgwick in Lower Styria.

Uppermost group, calcareo-arenaceous.—Calcareous sands and pebble beds, calcareous grits and oolitic limestones, containing many shells, some of these of existing species.

White and blue marl, calcareous grit, white marlstone, and concretionary white limestone with shells.

Middle group, calcareous.—Below this is a coralline limestone with shells, in one place 400 feet thick, associated with marls.

Lowest group observed.—Conglomerate with micaceo-calcareous sand, and millstone conglomerate.
Blue marly shale and sand, with shells analogous to those of the calcaire grossier and London clay.
Shale and sandstone with beds of lignite, accompanied by fluviatile and terrestrial exuviæ.
Conglomerates, grits, and micaceous sandstones.

The coralline limestone here mentioned serves as a good line to connect the sections along the line of the Carpathians. At Vienna, Murchison and Sedgwick give the following series :—

Alluvial beds? of löss and gravel, the latter containing bones of mastodon, tapir, anthracotherium, &c.
Fresh water limestone.
Leithakalk or coralline limestone and calcareous conglomerate.
Lower group.—Upper blue marls and sands, very rich in shells, yellow sand and shells.
Lower blue marls 300 feet, compared to London clay.

Transylvania, &c.—In Transylvania, Boué gives the series thus :—

Upper group shelly sands, marine and fresh water.
Sandy coarse limestone, equivalent of the Leithakalk.
Molasse.
Clay and marls blue and yellow.

And this applies to Moravia and the west of Hungary, where the lower beds are inclined toward the Carpathians.

Gosau Beds.—Below all these tertiary strata, in geological position, but raised to a great height in the Alpine region by powerful dislocations, occur those shelly marls and sands with conglomerates and traces of lignite, which have acquired celebrity from the researches of Murchison, Sedgwick, Boué, Von Lilienbach, and other geologists. The discussions on their relative age are even yet unsettled, because no sections can be obtained, under the difficult circumstances of the case, which put in a clear order of uninterrupted succession the whole mass of tertiaries, or allow a very confident deduction concerning the relation of all the parts taken separately. The obscurity of the subject is increased by the admitted indistinctness and variation of mineralogical character in the tertiary sands and conglomerates of the plains of the Danube. Yet it is not to be supposed that no inferences can be grounded on the laborious investigations of the eminent geologists above named. The Gosau shelly beds are limited below by the Alpine limestone at Gosau, and in the Rentersberg by the same limestone (hippuritic), covered by gray or reddish marls and marlstone containing a few fossils of the chalk formation: above, these beds are known to pass under the molasse of the plains north of the Alps. Two sections, derived from the labours of Mur-

chison and Sedgwick, will, with this understanding, sufficiently show the nature of the beds. The first is across the Valley of Gosau :—

Uppermost group.—Red and green slaty micaceous sandstone several hundred feet thick. (Cap of the Horn.)

Second group.—Green micaceous gritty sandstone, extensively quarried as whetstone, succeeded by yellowish sandy marls. (In the Ressenberg.)

Third group.—Vast shelly series of blue marls, alternating with compact limestone and calcareous grit; traces of vegetables above, abundance of shells and corals in the middle and lower part. (In the Valley of Gosau.)

Lowest group.—The above series gradually changes to beds of a more conglomerate character, which pass into red sandstone and marl containing gypsum; a coarse conglomerate, forming the base of the whole system, rests upon and *abuts against* the Alpine limestone. (Russbach.)

The discontinuity between the lowest part of this section and the top of the Alpine limestone is partially remedied in the Untersberg, where a series of four terms likewise appears.

Uppermost group.—A great succession of alternating masses of bluish micaceous marl, slate, clay, sandstone, and conglomerate. Some of these marls contain beds of gypsum and fossils resembling the suite of Gosau.

Second group.—Beds of blue micaceous slate clay, and greenish micaceous sandstone.

Third group.—Sandy micaceous marls, alternating with conglomerates and micaceous calc grit with nummulites. Subordinate to this system are red and variegated marls with gypsum.

Lowest group.—A great deposit of marl and marlstone, generally of a gray, but in some places of a red colour; containing a few fossils resembling those of the chalk formation.

These beds are conformed in declination to the Alpine limestones of the Untersberg.

Age of the Gosau Beds.—Murchison and Sedgwick conceived these Gosau beds to be the lowest of the tertiary series of the country, and to have so much analogy to the system below as to be properly regarded as one of the connecting links of the cretaceous and tertiary rocks. M. Boué ranked them with the green sand system. On appealing to the organic remains, we learn that the affinity of *genera*, and the proportion of univalves and bivalves, bring the Gosau beds to a tertiary type; an examination of the *species* leads M. Deshayes to declare (Lyell, vol. iii. edit. 1,) that none of the Gosau shells are found in any recognized tertiary stratum, but that some of the most characteristic species of Gosau occur in the green sand below the chalk at Mons in Belgium. His researches have led him besides to the following decisive general statement, that no shell has yet been found which is common both to tertiary and secondary strata! Our own impression on the subject, derived from comparing the statements of those eminent writers who have enjoyed the fullest advantages of original examination, can be of no importance on either side;

it will be more useful to set an example, unfortunately rare in such discussions of deliberate indecision, and to appeal to future discoveries. Two remarks, however, must not be omitted. Though all the instances upon record should be found strictly to agree (even when modified by further discoveries,) with that valuable and practical conclusion for which geology is indebted to Deshayes, yet this conclusion is not universal, and cannot be employed to predicate the result of any new investigations on the boundaries of successive systems of life in the strata. And again, though certain genera may not yet have been recognized among secondary strata, the deduction of the age of the Gosau beds from this source is of the same conditional character.

Molasse.—The primary and secondary Swiss mountains are bordered on the north by a vast thickness of conglomerates, sands, calciferous grits, and lignites with mammiferous quadrupeds. These are referred by Brongniart to the interlacustrine marine beds of Paris, but the shells as yet found in it are few. M. Studer, of Berne, has amply described this immense and disturbed deposit.

Subapennine Deposits.—The subapennine strata are all that remain to be noticed in these comparative sections. No one since Brocchi has been more successful in the examination of these strata than Lyell, and they furnish much of the evidence which supports his classification of the tertiary system into eocene, meiocene, and pleiocene formations according to the degree of analogy which the organic fossils of those groups bear to existing races of marine animals.* They are of enormous thickness (several thousand feet), and must have required very long periods for their accumulation in the Mediterranean, from which they have been uplifted to considerable elevations on each side of the secondary Apennine ridges. The mass consists of innumerable alternations of calcareous and argillaceous marl, light brown, or blue; but the variation of mineral character is slight through the whole series, and not at all sufficient to furnish permanent marks of separation into groups. It is altogether like the sediment which we may suppose to be quietly deposited on the bed of the Mediterranean by rivers which have left their coarser detritus inland. Beds of lignite are sometimes interstratified, as at Medesano, near Parma. Subordinate beds of gypsum interstratified with shelly marls and sand also occur in the Parmesan. Sandstone is also interstratified, and rarely compact limestone replaces a portion of the calcareous marls. The whole is covered in places, and unequally, by a coarse yellow sand and conglomerate, in which alternations of fluviatile and marine exuviæ are traceable, and other circumstances are observed which mark estuary or littoral action.

* These terms are derived from καινὸς (recent), combined with ἠὼς (the dawn), μείων (less), and πλείων (more).

This may be taken as the character of the *middle* subapennine formation. The tertiary strata in the hill called the Superga, in Piedmont, have been described by M. Brongniart and other writers, and from personal examination (with Murchison) Lyell has inferred that they are the *oldest* part of the tertiary system in Italy. Fine green sand and marl, and a subjacent conglomerate (the boulders being of primary rocks), compose these strata, which dip at the extreme angle of 70°, under the more horizontal bluish subapennine marls of the plains of the Tanaro.

Sicilian Deposits.—The most *recent* portion of the subapennine deposits is exemplified by Lyell in the tufaceous formations of Naples, the calcareous strata of Otranto, and probably the greater part of the tertiary beds of Calabria. But the most satisfactory view of the newest tertiary strata is obtained in the Val di Noto, Sicily. Since Dr. Daubeny's account of that island, the phenomena of its stratified rocks have excited much attention, and Lyell has been eminently successful in deriving from them important inferences concerning the relative ages and periods of elevation of submarine strata. The following is an abstract of his descriptions.

The whole series of strata in the Val di Noto is divisible into three principal groups.

The uppermost group consists of limestone, sometimes 700 or 800 feet thick, often corresponding in mineral character with the calcaire grossier of Paris, but often more compact. It is regularly stratified and cavernous. These characters, however, are liable to vary in different parts of the island. Near Noto it has the concretionary spheroidal structure of the form of the Italian travertino, and contains terrestrial vegetables. These strata prevail not only in the Val di Noto, but, as Dr. Daubeny stated, cap the hill of Castrogiovanni, 3,000 feet above the strata. The organic remains of this limestone (generally casts) belong, with hardly any exception, to existing species.

The middle group, not abruptly distinguished from the upper one, consists of white calcareous sand, sometimes with a tendency to oolitic and pisolitic texture, such as the travertino of Tivoli. At Floridia, near Syracuse, it changes to conglomerate with calcareous pebbles, associated with sandy limestone full of broken shells. In some parts of Sicily this group seems to be represented by yellow sand, exactly resembling that superimposed in the blue subapennine marls of Italy.

The lowest of the three groups consists of an argillaceous deposit of variable thickness, called *creta* in Sicily. It resembles the blue marl of the subappenines, and encloses shells and corals in a beautiful state of preservation. The shells belong, with few exceptions, to recent species.

Other marly strata, probably tertiary, occur below, with gypsum, sulphur, and salt.

Lacustrine Tertiaries.—A few cases, selected from the great number of tertiary lacustrine deposits, for the sake of some peculiar facts which they display, may now be introduced, to illustrate the condition of the surface of the land during the tertiary epoch. In general it is to be observed that, just as at the present day lakes sometimes occur on certain streams, in several parts of the valley, at different heights above the sea, and spread their waters over the Jura limestone, chalk, tertiaries, or primary strata, according to the nature of the country, so it was in the older time; and no criterion of the age of a fresh water deposit is to be drawn from the marine nature of the strata on which it rests, beyond the mere inference that it was posterior to such strata. If, as must frequently happen, the circumstances of these different lakes are unlike, the deposits in them may be related neither by similarity of order, nor identity of composition, but it is probable that some analogy will be traceable in their organic remains.

In the basin of Paris, gypsum occurs only in the lower fresh water deposit, yet the gypsiferous fresh water deposit of Auvergne is supposed by Brongniart to be of the age of the upper fresh water deposits.

Central France.—The fresh water district of central France occupies considerable tracts along the lines of the Loire and the Allier, and is extended northwards on the latter river, so as to approach towards the proper basin of Paris. Interesting phenomena are presented by these deposits, where they have been subjected to volcanic agency about Clermont, the Cantal, and Puy in Velay. Along the Allier, granite is the general basis of the fresh water strata, which consist of sandstone and conglomerate, containing pebbles of all the primary rocks of the vicinity, but not of the volcanic rocks. Above these are green and white very finely foliated marls, full of the small bivalve crustaceous shells of cypris; thin tufaceous limestones, sometimes full of the larva-cases of phryganidæ; and the highest group of all in a few places is composed of gypseous marls. The most singular fact mentioned by Lyell and Murchison, in their description of this country, is the remarkable condition of these groups. The lowest conglomerate series puts on almost exactly the appearance of the English old red sandstone, with its purple and green spotted marls, and even its nodular limestone or cornstone; and the limestone in the upper part of the series actually becomes oolitic at Vichy and Gannat, and yields a building stone like that of Bath, and of equal beauty; soft in the quarry, but gathering hardness by exposure. With what astonishment would the geologist, acquainted with the fossils of the English oolite, gather in this oolite of Gannat, land shells and bones of quadrupeds, like those of the gypsum of Montmartre!

The lacustrine formation of the Cantal rests in the same manner upon primary rocks, with sandy and gravelly beds below, gypsiferous marls, beds of flint and limestone above. This fresh water limestone, and its accompanying flints, are described by Lyell as possessing a strong resemblance in mode of arrangement to the marine chalk and flint; the flint of the fresh water, black within, white without, and undergoing the same changes of superficial colour on exposure as the chalk flints of England.

Provence.—The same geologists have been very successful in tracing the fresh water deposits of Aix in Provence, which have yielded a large number of fossil insects, some fishes, and land plants of existing genera. M. De Serres also has described this locality, and studied the insects with attention. The general basis of the Aix tertiaries is a rock of the oolitic system, inclined and contorted in position, with gryphæa, belemnites, and ammonites. The lacustrine deposits are in the lower part a series of carboniferous limestones and shale, with stony bituminous coal in several seams which altogether amount to five feet in thickness. The limestone is compact, gray, blue, and black, and resembles the mountain limestone of England. Fresh water shells (cyclades, melania, planorbis, unio) accompany these beds, and gyrogonites are found in the coal itself. Micaceous sandstones and shales, with earthy limestone and limnææ, come on above; and these are succeeded by red marl and fibrous gypsum, also characterized by the presence of limnææ and planorbes. Under and above the town of Aix, the upper series of the basin is observed to consist of red sandstone and conglomerate, covered by white and pink-coloured marlstone and marl; and above all is a triple succession of gypsum and marls, overlaid by white calcareous marls and marlstone, with calcareo-siliceous millstone and resinous flint, containing land and lake shells. It is in these beds that the fossil fish occur abundantly, and leaves and branches of flabellaria, laurus, buxus, &c. are found. The insects are obtained from a parting in the upper gypseous beds. They are, with one exception, all land insects; and from the united testimony of M. De Serres and Mr. Curtis, referable or nearly related to existing genera, principally of the orders diptera and hemiptera, some coleoptera and hymenoptera, but only one lepidopterous insect; sixty-two genera are particularly enumerated by M. De Serres. May we not compare this curious fact in tertiary geology, and the parallel case at Œningen, to the collection of insects, leaves, and branches, which, when swept down by spring or summer floods, affords a rich harvest to the entomologist on the borders of the rivers in the north of England?

Œningen.—The limestone quarries of Œningen, near Schaffhausen, have long been celebrated for abundance of mammalia, birds, reptiles, fishes, insects, and plants, identical or very similar to existing kinds.

The section of the whole deposit is given by Murchison, who brought from this locality, in 1828, one of the most remarkable fossils which has ever been found—the entire and connected skeleton of an animal resembling a fox. The upper quarries offer a section of thirty feet, the beds changing downwards from brown clay into cream-coloured indurated marl, and afterward into a fissile fetid marlstone, containing flattened shells of planorbis, small limnææ, and cyprides; to these succeeds light-coloured, fetid, calcareous building stone, beneath which is a finely laminated bed, containing insects, cypris, shells of anodon, and many plants; then follow two thin beds of fetid limestone, in the upper of which a large tortoise was found, and in the lower one the fox. Below are slaty marls and marlstones, limestone, and building stone, with a repetition of finely laminated layers of marl, with plants and fishes; the general base is the molasse of Switzerland. Excepting this animal, which is much allied to the common fox of Europe, all the other quadrupeds found here are rodentia. The insects and plants belong to European genera. Prof. Heer, of Zurich, has lately collected and investigated the extinct Flora and Fauna of these famous excavations.

These descriptions of some of the most interesting lacustrine deposits, will render it unnecessary to particularize other numerous cases in Switzerland, Germany, Hungary, Italy, and Spain, which present nearly the same phenomena, and appear to occupy the whole interval of time from the lower fresh water formation of Paris to the glacial era, and to be represented by an equally continuous series of detached desiccated lakes from that era to the present time.

Lignite.—There is, however, another kind of fresh water deposit which requires a short notice. Lignite, or wood coal, has long been known in France, in connection with the plastic clay group and other more recent strata, and also in the Isle of Wight. The same kind of carbonaceous deposit is of value in the molasse of Switzerland, and very extensively spread over the north of Germany, and in the valley of the Rhine; it also interlaminates extensively the marine tertiaries of the basin of Vienna and the border of the Carpathians: lignitic coal has therefore been considered as even peculiar to the tertiary era. This is not quite correct, yet the generalization is of more importance than perhaps we may at present perceive.

The whole mass of these lignites is made up of land plants, mostly or wholly of dicotyledonous tribes, and they are accompanied by marls, land and fresh water shells, and, in places, by the bones of paleotheria, anthracotheria, beaver, &c. The fixing of their relative age is hardly possible by evidence drawn from themselves alone, for the shells and plants are few, and the quadrupedal remains very local. If we attempt to fix their date by that of the marine strata which they divide, the uncertainty of the latter datum must, in a great

measure, at present frustrate the attempt. Perhaps the most recent deposit of this kind mentioned on the continent, is that described by De Beaumont as associated with the older diluvium, as it has been considered, which that author ascribes to the uplifting of the western Alps. This deposit bears marks of slow and tranquil accumulation in a lake, contains planorbes in the layers of clay which alternate with it, and sometimes shows as many as four beds; it rests on and is covered by pebbles, which indicate violent watery action.

It is highly probable that lignite has been formed at many periods, and that deposits of this kind will be found at intervals from the plastic clay, through the diluvial gravel and clays to the modern alluvial peat bogs, which they so much resemble in alternation and repetition of materials, paucity of shells, occasional occurrence of quadrupedal remains, and almost every obvious circumstance.

Lignite of Bovey Tracey.—Bovey Tracey, in Devonshire, is the only locality in England where tertiary lignites are worth working; the exact geological age of this deposit is not known at present. Pipe-clay of some value lies with it. Dr. Miller, in the *Phil. Trans.*, vol. li., describes this deposit in a very interesting manner. The whole series dips to the south about twenty inches in a fathom. The perpendicular thickness of these strata, including the beds of clay with which they are intermixed, is about seventy feet. There are about six of each, and they are found to continue eastward, in an uninterrupted course, to the village of Little Bovey, a mile distant, and probably much farther. The strata of coal, near the surface, are from eighteen inches to four feet thick, and are separated by beds of brownish clay, nearly of the same dimensions, but diminishing in thickness downwards, in proportion as the strata of coal grew larger; and both are observed to be of a more compact and solid substance in the lower beds. The lowermost stratum of coal is sixteen feet thick; it lies on a bed of clay, under which is a sharp green sand of seventeen feet thick, and under that a bed of hard coarse clay, into which they have bored but found no coal. From the sand arises a spring of clear blue water, which the miners call mundic water, and a water of the same kind, trickling through the crevices of the coal, tinges the outside of it with a blue cast, derived from phosphate of iron.

Amongst the clay, but adhering to the coal, are found lumps of a bright yellow loam, which burn with an agreeable scent. (Retinasphalt.) Some of the coal is black, and nearly as heavy as pit coal; this is called stone coal; but the most remarkable sort resembles wood in the grain and appearance so much as to be called wood or board coal. Some plants like grass and reeds lie in the alternating clays, which are in part carbonaceous.

The following section of the Meissner by M. Herndeshagen

(*Leonhard Taschenbuch*, 1817) gives the most usual relations of the brown coal and basalt of that celebrated locality:—

1. Dammerde.		
2. Greenstone and basalt, 50 to 80 fathoms		300 to 480 feet.
3. Schwül (blind coal), a bituminous laminated clay, hardly to be distinguished from true coal		½ to 5 feet.
4. Kohlenflöz, in all 3 to 14 fathoms thick, viz.:—		3 to 14 fath.
a. Stangenkohle (prismatized)	1 to 4 ft.	
b. Glanzkohle (sp. gr. 1·438)	3 to 18 ft.	
c. Pechkohle (sp. gr. 1·346)	3 in. to 3½ ft.	
d. Brownish black (sp. gr. 1·259)	3 to 4 ft.	
e. Light brown light coal (sp. gr. 1·230)	4 to 8 fath.	
f. Fossil wood, called stockwerk	6 in. to 4 ft.	
5. Liegende (sill or sole of the coal), sp. gr. 2·545.		
6. Triebsand		½ fath.
7. Blue marl, on the east of the mountain, with gypsum		10 to 15 fath.
8. More or less friable sandstone 1 fathom, then sandstone to the foot of the mountain on the east side, but on the west side muschelkalk.		

EXAMPLES OF ORGANIC REMAINS OF LACUSTRINE TERTIARIES.

PLANTS.

From M. Adolphe Brongniart.

Cryptogamia cellulosa.

Muscites Tournalii	Armissan near Narbonne.
squamatus	Longjumeau near Paris.

Crypt. vasculosa.

Equiset. brachyodon	Armissan.
Filicites polybotrya	Ditto.
Lycopodites squamosus	Paris.
Chara Lemani	St. Ouen near Paris.
tuberculosa	Isle of Wight.
medicaginula	Montmorency, Sanois, Trappes near Paris.
helicteres	Pleurs, Department de l'Aisne.

Phanerog. gymnosperma.

Pinus pseudostrobus	Armissan.
Taxites Tournalii	Ditto.

Phanerog. monocotyledonea.

Smilacites hastata	Ditto.
Flabellaria Lamanoni	Aix en Provence.
Endogenites	Montmartre.
Poacites	Aix.

Phanerog. dicotyledonea.

Comptonia dryandræfolia	Armissan.
Betula dryadum	Ditto.
Carpinus macroptera	Ditto.
Phyllites lævigata	Aix, Armissan, Pavia, &c.
Geslini	Aix.

Nymphæa arethusa	Longjumeau.
? Culmites anomalus	Ditto.
Carpolithes thalictroides	Ditto, Isle of Wight.
ovulum	Longjumeau.
Exogenites	Palaiseau.

CONCHIFERA.

Unio Solandri, Sow	Isle of Wight, Hordwell.
Cyclas	Aix en Provence.
Anodonta Lavateri	Œningen.
Mya ? gregaria, Sow	Headen Hill.
Corbula nitida, Sow	Isle of Wight.
Cyrena pulchra ?	Hempstead Bay, Skye.
Mytilus Brardii, Sow	Hordwell.

MOLLUSCA.

GASTEROPODA.

Planorbis rotundatus, Sow	Paris, Salinelle (Gard), Quercey.
cornu	Paris.
euomphalus, Sow	Isle of Wight.
prevostinus	Ditto, Paris.
Planorbis prominens	Salinelle.
compressus	Ditto.
lens	Isle of Wight, Paris.
cylindricus, Sow	Isle of Wight.
Limnæa fusiformis, Sow	Headen Hill.
minima, Sow	Ditto.
maxima, Sow	Binstead.
longiscata, Lam.	Headen.
pyramidalis, Sow	Ditto.
columellaris, Sow	Hordwell.
cornea	Paris, Colle en Siennois.
fabulum	Paris.
ventricosa	Ditto, Bruere. (Cher.)
inflata	Bruere.
cylindrus	Ditto.
strigosa	Le Locle near Neufchatel.
elongata	Paris.
acuminata	Ditto.
æqualis	Salinelle.
pygmæa	Ditto.
ovum	Paris.
Paludina affinis	Salinelle.
impura	Quercy.
Hammeri	Isle of Wight, Bouxweiler.
carinata	Paris.
Ancylus elegans	Hordwell.
deperditus	Salinelle.
Melania fasciata	Isle of Wight.
Melanopsis carinata	Newport, Isle of Wight.
brevis	Hordwell, &c.

Phasianella orbicularis .... Shalcomb, Isle of Wight.
angulosa .... Ditto.
minuta.................................. Ditto.
Potamidum Lamarckii........................ Paris, Aurillac, Nonette, near Issoere.
acutum .... Isle of Wight.
ventricosum............................ Ditto.
Indusia tubulata? .... Moulins, Auvergne, Colle.
Cyclostoma truncatum............................ Paris, Carnetin.
elegans antiquum..................... Paris.
mumia .... Ditto.
Helix globosa.................................... Shalcomb, Isle of Wight.
Lemani .... Paris.
Desmarestina.......................... Ditto.
Ramondii................................ Orleans, Auvergne.
Cocqui .... Ditto, ditto.
Bulimus pygmæus .... Paris.
terebra .... Ditto.
atomus.................................... Paris, Le Puy.
pusillus .... Ditto.
Pupa Defrancii.................................} Paris and Auvergne,
muscorum..............................} in a piperine.

ARACHNIDA, INSECTA, &c.

Aranea.................................. Aix in Provence.
Phrynus.
Coleopt. Dyticus.
Staphylinus.
Buprestis.
Melolontha.
Curculionidæ........................ 10
Trogosita.
Hylophagidæ........................ 5
Orthoptera.................................. 8
Hemiptera 20
Neuroptera. (Libellulidæ.)
Hymenoptera 8
Lepidoptera................................ 2
Diptera.................................... 15

FISHES.

Mugil cephalus.................................. Aix in Provence.
Perca minuta.................................. Ditto and Paris.
Cyprinus squamosus .... Ditto ditto.
bipunctatus............................ Œningen.
jises .... Ditto.
capito .... Ditto.
minutus................................ Paris.
ictus.................................... Rochesaure. (Ardeche.)
tinca.................................... Cadix.

CHAPTER XV.

DEPOSITS OF THE MODERN ERA.—MODERN CAUSES IN ACTION.

Relation of Terraqueous Agencies in Ancient and Modern Eras.—Having now concluded our descriptions of the strata and aqueous products recognized in the crust of the globe, and also traced the effects of subsequent extraordinary inundations upon the surface, arising from local changes of level or general internal convulsions, it remains to be seen whether the causes now in action in the modern economy of nature are of the same *kind* as those which were formerly concerned in producing the arrangements and disarrangements observed in the crust of the globe.

This is the true cardinal point of theory. According as the one or the other conclusion on this point be adopted, we may attempt to explain the ancient phenomena by modern laws of nature, and thus connect the present and the past, the extinct and the existing history of our planet into one system of progressive change, according to the school of Hutton, Playfair, and Lyell; or suppose that in the chaotic infancy of our planet, laws peculiar to that period prevailed, and properties of matter were unfolded then which never show themselves at present; and that the ancient rocks and organic bodies belong to a wholly distinct set of causes, were the produce of a peculiar creative impulse, no longer permitted to operate on the finished and man-inhabited planet. The Wernerian cosmogony bears very much this aspect.

But though, put thus in direct opposition, the rival hypotheses appear to have no point of union, we find, in fact, that between the opinion of Hutton, who considers creative nature to be perpetually in progress,—the same to-day, yesterday, and for ever—and the dogma of Werner, that the world was made by a certain settled sequence of events, to which nothing similar now happens, every variety of theory is adopted and defended. We may, however, with rigid accuracy and much convenience, rank them in three classes.

1. The favourers of Hutton's and Lyell's views, who maintain that the causes now in action to change the level and alter the relations of the masses of matter in and near the crust of our globe, are those which have ever been in action, identical in kind, and equal in degree, in all times past, and which may be expected to continue the same, in kind and degree, through the future.

2. **Views of the English School on this Subject.**—The general school of English geologists, who have always maintained, and laboured to

prove, that the causes operating on the surface and in the interior of the earth have remained through all times past unchanged in kind, and are still operating with the same tendencies as they always did, but often on smaller areas, and with less effect. This view of the subject has a double aspect. English geologists have generally believed that as volcanos were supposed to become languid through want of fuel, the *circumstances* under which the modern operations of water and fire are manifested in the general economy of nature, approach more nearly a state of equilibrium or saturation, and therefore afford no opportunity for the same extraordinary display of energy as in ancient times; but since the relative periods of the great convulsions which have elevated chains of mountains, and given new boundaries to the ocean have been investigated upon sound principles, the mind has become gradually familiarized to another notion, and habituated to contemplate long periods of ordinary and regular action of natural causes, interrupted by transient, local, or general convulsions. According to this modification of the hypothesis, the present is a period of ordinary and regular action, succeeding upon an epoch of violent disturbance.

3. The old notion of despairing speculators in cosmogony, who found it easier to cut the Gordian knot, by flatly denying the analogy of modern and ancient operations, and either referring the whole beautiful order of the ancient works of nature which they could not comprehend, to a momentary fiat of Deity, or to the rude and prolonged confusion of elements in chaos.

This is the only notice we shall take of that mere dream of indolence and deficient observation; for we have already proved that the stratified rocks are certainly analogous in all points to the products of modern waters, and that the unstratified rocks clearly prove their special origin from fire.

As in our accounts of the construction of the earth's crust we have resolved to separate the results of the ancient operations of fire and water, so in our views of the modern effects of these agents, the same plan will be followed; and, without stopping at every point to settle the precise amount of inference due to every datum, we shall present a connected view of the continual effects of the atmosphere, rains, springs, rivers, and the sea, on the surface of the globe, before proceeding to the changes occasioned by more occasional eruptions of igneous agents from below, volcanos and earthquakes, and other connected phenomena. Some general inferences, suited to the present state of the science, may occasionally be ventured, and perhaps many years must pass before any one acquainted with the peculiar temptations to insecure hypothesis which sciences of observation hold out, will venture to dignify his imperfect generalizations with the flattering title of a theory of the earth.

Wasting Effects of the Atmosphere.

The gradual wasting of the surface of the higher parts of the earth is an important element in geological theory, and it is scarcely to be supposed that any geologist can be so entirely engrossed with the contemplation of the ancient operations of water in producing the stratified crust of our planet as to neglect the consideration of the analogous effects which are in progress at the present time. The following examples of the varied effects of atmospheric influences, in modifying the surface of the erections of man and the works of nature, are derived from the writer's own observations, and it is to be supposed that they form but a small part of the current information on the subject.

The wasting effects of the atmosphere are those initial or preparatory processes by which earthy materials are provided for rivers and the sea to transport and deposit in new situations.

These processes, as far as they depend on the atmosphere, are chemical when the atomic composition and the properties of the parts are changed, mechanical when their state of aggregation is altered; and this may happen by general humidity, variations of moisture, variations of temperature, or precipitations of rain.

It is not, however, always possible to distinguish accurately the effects of these several causes. Many natural agencies are often concerned in one operation, and the general result is the sum or the difference of their effects. The chemical effects of the atmosphere are evident in buildings and on the surface of certain rocks. The same process which slowly reconverts the mortar of walls into carbonate of lime frequently causes the pulverization and bursting of the bricks, in consequence of the expansion of the small masses of lime which they contain.

The surface of bricks is often covered with a saline efflorescence, which is generally nitrate of lime, but sometimes muriate of soda. The surface of the yellow limestone near Doncaster is sometimes covered with a nitrous efflorescence, and so is the calcareo-magnesian mortar made from it.

Waste of Felspathic Rocks.—The exterior of most uncrystalline rocks and buildings seems to be slowly eaten away by the moisture and carbonic acid of the air; but the influence of this destructive agent is most remarkable among the felspathic rocks, whether like granite they are originally crystalline, or like millstone grit composed of fragmented masses. The felspathic portion of the hypersthene rocks of Carrock Fell is so wasted that the crystals of hypersthene and magnetic iron are projected from the surface considerably Some greenstone dikes are thus entirely decomposed to great depths from the surface, and whole rocks of granite, secretly rotten, wait

only for an earthquake or a water-spout to be entirely reduced to fragments. Those who have seen the crumbled granite of Muncaster Fell in Cumberland, or Castle Abhol in Arran, surrounded by heaps of its disintegrated ingredients, must have been struck by the importance of this phenomenon in reasonings concerning the origin of many stratified rocks.

Both carbonic acid and oxygen act very decidedly upon the metallic, and particularly the ferruginous ingredients of rocks, and thus swell and burst them to pieces. Sometimes, however, this very cause seems to harden and bind together the rock, and to render it more durable; and in general there is no certain test of the durability of any stone but experience under the same circumstances. The Bath stone, so permanent amongst its native hills, perishes in the salt air of Norfolk, and few calcareous freestones of any kind will long resist the carbonaceous atmosphere of London.

343 Balkan.

Preserving Power of the Ground.—It is worthy ot remark, that sculptured stones buried under ground are perfectly and even wonderfully preserved, while their fellows left exposed to the sky have been almost crumbled to dust. A fine example of this was noticed in the course of the excavations for the Yorkshire Museum, by which the statues which once stood between the arches of the nave of St. Mary's Abbey were discovered, some with blue others with red drapery, one with gilded hair, all retaining the most delicate chisel marks. A few yards from them, at the west end of the church which they once adorned, the atmospheric influences have nearly

obliterated a beautifully sculptured wreath of leaves round the doorway, so that antiquaries have doubted whether they were meant to represent the vine or the ivy.

Waste from Humidity.—Frequently, in looking at buildings composed of porous materials, like the Portland stone, or a grit freestone, we observe the parts which are overhung by a ledge, and thus kept in a state of continual shade and dampness, to be more rapidly consumed than the projections; but the parts which hasten soonest to decay are those near the ground. The same rules are exemplified in many remarkable rocks, as, for instance, in the quartzose conglomerates of the old red sandstone of Monmouthshire and the millstone grit of Brimham Crags in Yorkshire. The "Buckstone," near Monmouth, is a huge rock inversely conical, expanded above into a large area, but contracted below by continual waste to a narrow base of attachment. This process, a little further continued, might convert the Buckstone, as probably some of the stones of Brimham have been converted, into a "rocking stone."

From Changes of Heat and Moisture.—In northern zones the variations of heat and moisture are greatest on the south and west fronts of buildings, and in consequence those fronts to our cathedrals decay most rapidly. This is remarkably the case with the grand cathedral of York, built of magnesian limestone, which is in many places quite consumed on these fronts, but comparatively uninjured on the northern face.

The weathering of the surfaces of buildings by the fluctuations of heat and moisture is partly dependent on the structure and composition of the stone. The flagstone of Yorkshire is in many houses at Bradford gradually decayed grain by grain, so that the surfaces of the stone, continually renewed, and never permitting the growth of lichens, appear always neat and clean. The magnesian limestone of the same county, often traversed by veins of calcareous spar, presents frequently a cellular or honeycomb appearance, in consequence of the projection of these veins above the excavated limestone; but the coarse shelly beds of the Northamptonshire oolites, and the irregularly laminated millstone grit, are decomposed in lines corresponding to the inequalities in the composition of the stone.

In these cases the stone appears to undergo gradual and continual waste, but sometimes the whole surface exfoliates. Basalt very frequently suffers this kind of waste, granite not seldom; and it has been supposed in these instances, that the atmospheric action merely discloses the latent concretionary structure of the rocks.

The following examples require a different explanation. The bridge over the Wear, beneath the western towers of Durham cathedral, built (about 60 years ago?) of a sandstone associated with coal, is ornamented with a balustrade, and the little pillars are worked

with various swellings and mouldings. In crossing this bridge many years since, the writer struck one of the balusters with his hammer, and being much surprised with the hollow noise which ensued, stopped to ascertain the cause. It was found, in many instances, that a thin, external coat of stone, parallel to the mouldings, was entirely separated from the internal nucleus, and ready to scale off upon the slightest blow. The western front of the ancient and beautiful little church of Skelton, near York, built of magnesian limestone, shows the same kind of decay in a direction across the bed of the stone. The Yorkshire flagstone is occasionally used to make curb stones of two feet in height, the laminæ being placed vertically, and the block worked above to a semi-ellipsoidal figure. Even these laminated stones frequently exfoliate parallel to the tooled surface. The ramparts of Zurich are built of sandstone, belonging to the tertiary system (molasse), and the stones are cut with a boss along the middle and a depressed border. Desquamation happens parallel to the artificial surface.

Since, in these various instances, desquamations are found to occur parallel to the surface, without reference to the internal lamination of the stone, the mere circumstance of exfoliation seems insufficient to demonstrate the originally concretionary structure of basalt and granite. It is, nevertheless, very probable on other grounds, that basaltic pillars, if permitted to assume their natural shapes, without pressing one against another, would resemble a number of superimposed spheroids.

All the cases of desquamation seem to arise from an alteration of the degree of coherence of the stone, whereby the external crust is made to expand and contract differently from the internal parts, and, in consequence, is soon separated from them. The surface of stones long exposed to the weather is frequently much indurated, while the inner parts remain soft. (This is the case in the outer circle of Stonehenge. W. Smith.)

From Frost.—Frost is likewise an important agent in reducing to smaller masses the materials of the earth. Some stone, if brought to the suface in winter full of its "quarry water," will break in pieces directly. Advantage is taken of this circumstance by the slate-workers of Stonesfield and Collyweston, who quarry their stone in the winter, taking care to shield it from the sun and the wind till the frost has acted upon it, with the aid of affused water, if necessary, which, by disclosing the natural fissility of the stone, permit the blocks to be cleft into thin, sound, roofing slate. Landslips in mountainous regions are, probably, much accelerated by the power of frosts. In ascending the Righi from Weggis, on the Lake of Lucern, we are much struck by the extraordinary length and continuity of the joints of the nägelflue. It is from these natural partings that

the landslips fall, when repeated rains, snows, and frosts have worn or burst them open, and the water passing down them undermines the foundation of the cliff. Thus huge blocks, liberated from their attachments, roll down the steep descent, or half the summit of a mountain slides upon its argillaceous bed. Vast portions have thus slipped from the Righi towards the isthmus which divides the lakes of Zug and Lucern, and others are preparing to follow. The fissure is already opened parallel to the edge of the precipice, and pervious below, so that a stone thrown in at the top, is said to fly bounding out at the base.

Effects of Rain.—We come now to the effects of rain, and without dwelling on the general degradation of the softer surfaces of the earth caused by this agent, we shall proceed to show, that within the historic era hard and durable stones have been greatly furrowed by the rain, and that in more ancient periods, the precipitations from above have carved themselves channels of various kinds, and sometimes occasioned real though miniature valleys of great length and continuity.

On Monumental Stones, &c.—Many Druidical monuments in the north of England are constructed of coarse millstone grit, a rock admirably suited for yielding those enormous blocks preferred by the ancient architects. Three huge Druidical stones, now standing near Boroughbridge, called the "*Devil's Arrows*," present us with a most instructive lesson on the ultimate fate of all human erections exposed to the ravages of time.

The rain, beating for 2,000 years upon these venerable pillars, has cleft their tops, and ploughed deep furrows down their sides. The grooves are deepest at the top, and become wider and less distinct towards the bottom; they cross indifferently the false-bedded layers of pebbles, and go directly downwards. One of the stones leans remarkably and threatens to fall, but an examination of the furrows shows the inclination to be of most ancient date, for they descend much farther down the pillar on the upper inclined face than on the under.

Similar effects of rain are visible to a greater extent on the bold crags, like Almias cliff and Brimham rocks, which crown the summits of so many hills of north-western Yorkshire, from some of which the Devil's Arrows were obtained.

In the valleys of Switzerland (Sarnen) blocks of limestone, which have fallen from the mountain sides, have been furrowed in the same way since their descent.

On Rocky Cliffs and Floors. — The carboniferous limestone of England has been little employed in building, except partially in old castles, where it seems durable, and they who know the magnificent ranges of scars which begird the hills of Derbyshire and Westmoreland will acknowledge that few rocks seem more likely to endure the rage of the elements. But yet close inspection of these giant cliffs

will prove that time has been busy there. The dry and bleached aspect, and the smoothed angles, show plainly the wasted surface. Those who have stood on Doward Hill, near Monmouth, to contemplate the rain-furrowed white limestone there, will not need another example. In the north of England analogous and more remarkable instances present themselves in the wide limestone base of Ingleborough, and in Hutton roof crags near Kirkby Lonsdale.

The vast limestone floor which supports the cone of Ingleborough is marked in all directions by natural fissures, and divided into compartments like a map.

If one of these compartments be examined in the western part of the mountain, its surface will be found scooped into little hollows which unite into a common channel, and terminate by indenting the edges and furrowing the sides of the fissure. They are, in truth, valleys in miniature, separately produced, by the drainage, so to speak, of the several blocks.

The mere decomposing effect of the atmosphere produces on the edges of the stone a different effect, by wearing away the softer laminæ, but the smooth surface of the miniature valleys, their regular descent, winding course, and union into a common channel, show that they were fashioned by the repeated operation of descending rain.

This scar is nearly level, but in Hutton roof crags we have an opportunity of tracing the rain channels over an immense surface of bare limestone rocks lying nearly level on the hill top, but sloping rapidly down the sides to the east and south. On the level top of the hill the stones are variously worn in hollows and grooves irregularly united and running in different directions, according to little variations of the ground; but on the steep east and south slopes the channels are extended into long furrows, which, uniting at acute angles, enlarge, widen, and descend the hill side, in lines following exactly the declination of the rocks, and stopped only by the few and distant fissures beyond which other systems of concurrent grooves begin.

Rain Channels like Miniature Valleys.—It is impossible by drawings, or descriptions, to convey such an idea of the appearances of the Hutton roof crags, as to awaken in others the deep impressions which are fixed for ever in the mind of the observer. The astonishing resemblance which these little rain channels present to the great system of valleys which undulate the stratified rocks, seizes upon the imagination, and we re-examine all our notions of the origin of these great undulations. The fissures in the limestone rocks which stop and swallow up the gathered streams, are analogous to those longitudinal valleys beneath the escarpments of the oolites, and the chalk by which the rivers are turned at right angles to their earlier course, while the lower edge of the fissure corresponds to the escarpment itself, with its new system of denudations.

To see these rain and time-ploughed furrows winding in uncertain directions over the horizontal limestones on the hill top, like a slow river in a level plain, but running a straight downward course on the slopes, like a stream descending from its parent mountains, is enough to impress on every beholder a secure conviction that the excavation of valleys must be explained upon similar principles; that, as the feeble currents of descending rain, aided by long time, have been sufficient to plough their little courses, so the greater action of existing streams has been sufficient to work out their *actual channels*, though the excavation of the *broad valleys* in which they run, may have been accomplished by more violent and voluminous waters, flowing in directions predetermined by ancient subterranean movements.

Effects of Inundations.—It is probable that the slow but incessant action of rain, beating perpetually on the hard and the soft surface of the earth, and removing grain by the materials loosened by the expansive agency of frost, moisture, and chemical changes, may be, in a given long series of years, more important in its effects than the violent water-spout, or the ravaging inundation of a bursting lake. Yet the effects of water-spouts are tremendous in countries composed of easily destructible or unequally indurated materials. A water-spout which fell on the mass above Kettlewell in Yorkshire, committed the most terrible ravages in the narrow valley of the Wharfe, near Kettlewell and Starbottom. On the sides of the mountains in Cumberland, traces of these visitations seem utterly ineffaceable; and the memory of the sudden bursting of the Peat Bog above Keighley, will long be preserved in the valley of the Aire. The floods which rushed simultaneously from the Cairn Gorum and other mountains, in August 1829, over 5,000 square miles of Aberdeenshire and other counties, were of prodigious fury, removing hundreds of tons of large stones, whole acres of woodland, and almost hills of earth. The desolating effects of the bursting of the ice-dam which had formed the temporary Lake of Bagnes, are matters of history. The moving mass of water, mud, and monstrous rocks, which swept with violence down the valley of the Dranse, carried away forests, houses, bridges, cattle, and men. In six hours and a-half it passed through an unequal and irregular course of forty-five miles, till its waves were lost in the Lake of Geneva.

Glaciers are likewise to be enumerated among the powerful agents by which the higher lands are wasted, and materials provided for the raising of the lower. As the summer heat melts every year the lower portions of these long winding rivers of ice, and the heated ground thaws, and the gathering water dissolves their foundation, the whole mighty mass of snowy ice slides downwards on its failing bed, ploughs up the stones, breaks up the rocks, and adding their spoils to the accumulations of the avalanches, throws to the sides

huge banks of rubbish, provincially called *moraine.* The foot of the glacier is thus surrounded by an immense hill of loose materials which gradually find their way into the stream that issues beneath.

344 Track of a Glacier, Mer de Glace.

Descending Streams and Rivers.

The wasting effects of the atmosphere, noticed in the preceding section, are sensible in all regions, and therefore in every country some materials are provided for the streams to transport. But the proportion of matter thus prepared in mountainous countries is so vastly greater than elsewhere, that in general the less conspicuous effects of the same causes in lower regions are overlooked. The common notion respecting the action of alpine streams appears to

be, that *these* are the principal agents of destruction upon the faces of the mountains, and that it is to them that the actual waste of the surface is attributed. But though these streams are indeed powerful agents of excavation, their principal influence is of quite another kind, and it is chiefly by the *disposition* of the materials brought into them by rains, avalanches, and water-spouts, that they effect such important changes.

Erosive or Excavating Action of Streams.—In considering the action of streams and rivers, we must distinguish between their powers of eroding or *excavating*, and of *transporting* solid matter.

The former is occupied on the channel and floodway, and its effects have relation to the *consolidation* of the matter traversed, and to the rapidity and volume of the moving water. About their sources, and for a long part of their early course, streams deepen continually their channels, and wear away their barriers of rock: but in their broad expansions near the sea, this power of excavation wholly ceases, as a general law, and is only evinced in particular cases, as when great bands are cut off or banks are undermined.

We have abundance of examples in all our mountain regions of the actual excavation of their channels by the rivulets and rivers. In the district of Aldstone Moor, the south Tyne runs to the north from the side of Cross Fell, for some miles along a slope of shale, over the Tyne bottom limestone. In this shale, which is itself excavated into a broad valley, the river has evidently cut its own narrow yet sufficient channel; and no contrast can be more striking than that here afforded by the mighty valley of Tynedale, 1,500 or 2,000 feet below its bordering mountains, and the little channel holding the waters of the River Tyne. Every river in this manner works out its own channel in elevated regions, and in lower ground the soft clays and sands yield a passage to the feebler currents. In the level regions, along the rivers of Yorkshire and Lincolnshire, the channels have been many times changed, even by those sluggish streams, and still more in the deltas of the Rhine, the Nile, and the Mississippi; and among the Alps, this fluctuation of the river courses is excessively irregular. No doubt, then, can remain of the fact that rivers and running waters excavate and alter their channels.

Lyell has given a remarkable case of the *recent* excavation in a bed of modern lava of a channel from 50 to several hundred feet wide, and 40 to 50 feet deep, by the river Simeto, flowing from Etna. Scrope has also shown similar phenomena to have happened in the volcanic region of Auvergne. In these cases the action of the river has probably been excited by the flowing of a current of lava across its course, so as to dam up the waters, and give them something of the force of a cataract.

Waterfalls, &c.—The waterfalls and cataracts upon the line of a

stream afford some curious points of study. It is especially in these cases that the increase of excavating power, derived by a river from the solid matter which it transports, is most sensible.

A cataract is formed upon the river Eden, in Westmoreland, near Kirkby Stephen, by some remarkable beds of calcareous red sandstone conglomerate, and the pebbles which the river brings down, here contribute with the whirlings of the water to excavate many deep perpendicular pits, similar on a small scale to swallow holes on the mountain limestone ranges, or those romantic cavities on the Caldew in Cumberland. Below many waterfalls in Wales and Scotland, the same effect is produced.

345 Deposit of Travestin at a Cascade.

But the most characteristic effect of a cascade, is that ceaseless undermining of its base and sides, and consequent rupture of the spout or edge of the fall, which causes by slow degrees the cascade to retire farther and farther up the mountain side, and produces those awful and still deepening portals of impending rocks, which so much aggrandize the sublimity of a noble *waterforce.* (In Norway, *fors.*)

This effect may be excellently observed in the carboniferous limestone district of the north of England, where so many beautiful streams leap from the beds of limestone over perishing shales and sandstones, and rising in foam sap and undermine the base of a large semicircular cliff, till at length the solid limestone crown gives way, and the insatiable river renews its destroying attacks. The same thing is seen in many of the Swiss waterfalls, particularly in the manifold falls of the Giessbach.

Lyell very ingeniously applies the acknowledged fact of the recession of the Falls of Niagara, which appear to have been pushed back several miles, at the rate of 40 or 50 yards in 50 years, to the pos-

sible discharge hereafter, through the St. Lawrence, of the waters of Lake Erie. Such a discharge would, of course, occasion a local *deluge;* but the lake is so rapidly filled up by sediment, that it is a question whether it will not become dry ground, before the falls of Niagara shall have been pushed back so far as to be capable of emptying it. The fall of the Rhine at Schaffhausen is a grand exhibition of the erosive power of water, particularly the wearing of the base of the two island pinnacles of limestone, which now stand proudly in the midst of the currents, but will eventually be hurled down the thundering cataracts.

346 Falls of Niagara.

Transporting Power of Streams.—In considering now *the transporting action of streams*, we may distinguish between such as flow through valleys of uniform declivity without lakes, and such as pass through broad receptacles of water, before arriving at the sea. As examples of the former, we may take many rivers of England; for the latter case, several rivers of England, Wales, and Scotland might be named, but much grander phenomena of the kind are witnessed among the streams which flow down from the snow-crested Alps.

Rivers without Lakes.—A certain velocity of current is requisite for the transport of every kind of earthy matter; the finer the matter the less force will move it along. Hence in the lower parts of rivers, where their course relents, and they approach the sea, though they can no longer, as in their youthful energy, remove rocks and transport loads of sediment, their waters are muddy, and their channels and sides receive continual augmentation. Such a river as the Yorkshire Ouse is very instructive. As its branches descend from Shunnor Fell, Cam Fell, and Whernside, they transport daily

and hourly from those elevated sites the materials accumulated by atmospheric changes and mechanical attrition; the soil, the stones, the loosened rocks, grain by grain, and piece by piece, move onward with the current, and thus the whole mountain region, by a slow yet not imperceptible progress, is lowered in height, and its wasted spoils swept away for ever. But let us follow this process. Wherever the valley originally presented great inequalities, these are constantly diminished by the upfilling of the hollows, and at length the originally rugged chasm is changed by *additions* and *upfillings* into the smooth, evenly declining hollow, which, because of that smoothness and uniform declination, is supposed by many to be entirely a valley of denudation. In this process, the lateral action of rains and inundations from the sides of the valley, is a very important auxiliary. Any one who contemplates the valleys of the Jura, near Schaffhausen, and sees them in many cases rugged on the sides, and evidently traced by nature in a fit of convulsion, must be struck by the smooth, even, equally declining *plane* of their bottom, which cuts the rude precipices of the sides, and clearly indicates a subsequent powerful modification of the original harshness of the chasm. Still more abundant is the deposit of sediment as the stream glides into lower ground. There, above its narrow channel, rise the broad meads which, with every fresh inundation, receive a new coat of sediment, and above these swell the real boundaries of the valley, often consisting of water-worn materials, gravel and sand, left there by ancient floods of greater power, flowing at a higher level. As we approach the sea, when the tidal currents meet the freshes, the suspension of motion permits a great part of what sediment still remains to discolour the water to drop on the bed of the river, and its alluvial banks. Thus the streams become choked, their channels sinuous, their beds elevated, and the banks which confine the river, heightened both by nature and art, look like the ramparts and terraces of a lofty military road rather than the boundaries of a river giving passage to the drainage of the neighbouring country.

The same process at the mouths of rivers pushes their channel and their banks outwards into a cape or headland, and contributes to extend the whole breadth of the bordering coast, so that by the waste of the uplands the low land is filled up, the river channels are raised, the coast is extended into the sea, and the sea filled with shoals and sand banks. Thus the mouths of the Po, the Rhine, the Nile, the Euphrates, the Ganges, and the Mississippi, have formed for themselves those broad deltas which, within the historic era, have transformed ancient ports into inland towns, and carried fertile pastures into the area of the sea.

The substances transported by the stream, and deposited along its sides, are of course such as the hills around its sources, and above

its channel, furnish; and according to the nature of the country, the almost incessant accumulations of earthy matter which thus take place, may be varied by the interposed layers of vegetable reliquiæ. In tropical and warm regions, and in unenclosed countries, this must be the case to a far greater extent than an acquaintance with European rivers would lead us to expect. The mighty forests of America, untouched by human industry, must annually furnish to the great rivers which intersect them, an immense spoil of trees, which being easily supported by the current, will be carried even to the sea, and either deposited at the river mouth, or drifted away on the waves.

Arrangement of Materials.—The arrangement of the materials brought down by the streams is in general regulated by a tendency to the production of a level surface, and thus the original inequalities of a valley are continually lessened. In a high region like the Alps, the rough streams leave in the higher level chiefly a collection of pebbles and sand, and they are left in much local confusion; but still the general effect is a uniformly declining plane, through which the capricious stream finds itself new channels, and thus continually shifts its deposits over the whole, broad, pebbly surface. Such effects may be well seen on the line of the Arve, as it hurries down from the glaciers of Savoy. On the contrary, in the lower and more level expansions of a valley, where the gentler waters transport only fine sediment and vegetable reliquiæ, these materials are arranged in most exact parallelism over a large extent of plane surface, and by counting the laminæ of deposition, some useful notion may be formed of the period occupied in the process. On the borders of streams which are periodically swollen by rain, as in the tropical regions, or by the melting of snows, as in those which descend from high mountain countries, this mode of computation of the laminæ may even be trusted so far as to determine the number of years employed in producing a given depth of deposit; and even in districts where the rivers swell irregularly at uncertain intervals, there might be an *average rule* for the same purpose deduced. Nor would the accumulation of a short period of time, tried by this test, appear inconsiderable. In a single season, the rivers of Yorkshire, aided by the sea, deposit many inches of rich soil upon the level peat moors which adjoin their estuary; and at Ferrybridge, at the point where the tide, formerly flowing up the river, neutralized the freshes of that river, many of the modern works of man, as oars of a boat, a coin of England, were found buried under the alluvial sediment, which contained petrified hazel branches and nuts, bones of the stag, &c.

From what has been said of the action of rivers, it is evident that their effects upon the physical features of a country are more varied and interesting than has been generally perceived by those who have written on the much controverted question of the origin of valleys.

The tendency of all descending streams of water is the same,—to equalize the surface of the earth, to remove all its ridges and asperities, and to smooth all its gulfs and fissures.

The degree in which they respectively perform this depends, *first*, on the amount of atmospheric and local influences in wasting the surface of the higher ground, and bringing materials for the rivers to act upon. Hence the rapid waste of high Alpine tracts exposed to fluctuating heat and cold, to storms, avalanches, and glaciers. Hence the streams of sand and pebbles, which rush from the grit-stone hills of England, and, on the contrary, the almost unsullied purity of the springs which break from the carboniferous limestone.

The *second* circumstance which determines the modifying power of the river is its own volume and velocity, and these are principally dependent on the physical geography of the region. The datum of the volume of water flowing in any valley is principally useful for comparison with the *amount of effects;* the *kind of effect* produced is determined by the *velocity* of the current.

If we conceive that in its first fury a river may have power enough to sweep along even large blocks of stone, but that its velocity gradually diminishes, there will be a certain point, where these large blocks will be left by the enfeebled current, pebbles will roll farther, coarse sand will travel beyond, and the finer sediment will be moved on till the languid waters permit their slow and equal deposition. This gradation of deposits is always observed in examining valleys of sufficient length and elevations. The deposits in the upper parts are tumultuous and confused, in the lower regions level and regular.

A *third* circumstance, of still more importance than the others, serves to regulate the action of the river. This is the *form and character* of the valley itself. However produced, there can be no question that the present aspect of almost every valley in the world is smoother and more equalized than it was formerly, since we see evidently and take as a principle, that the characteristic effect of modern causes in action is to reduce continually the inequality which remains. We may, therefore, easily, for each valley, restore in imagination its ancient condition, remove the sediment from its expanded meadows, and leave, instead of level or gently sloping plains, that wind smoothly round the hills, and ascend far up toward the sources of the stream, deep chasms between cliffs rent asunder by convulsion, and ridges of rock confusedly crossing the gulfs of the strata. That such has been the origin of many valleys is perfectly evident. That these may have been partly cleared, and others wholly occasioned by violent floods, sweeping over and denudating the land during its elevation from the sea, or by some violent catastrophe at a subsequent period, is also very probable, or rather may

be considered as proved. But without entering on these questions, we may content ourselves with the *datum* that the fundamental features of valleys are not the result of the excavating action of their streams, but that valleys have been in part filled up by the accumulations brought by their own rivers, and that their present smoothness and uniformity is really the result of the modifying powers of the sea, the atmosphere, local influences, and the river, exerted through long time upon a ruder channel, left by more violent and transitory agents.

Rivers with Lakes.—Let us now see what peculiarities in the effects of rivers are occasioned by the circumstance of their traversing quiet lakes. Two things are here to be attended to. First, the lake causes, according to its extent, a more complete deposition of the sediment brought by the rivers than is occasioned by the most level dry area of a valley; secondly, the materials dropped in the lake are regulated by somewhat different laws from those which direct their accumulation on the common surface.

When a river charged with sediment expands into the waters of a lake, its motion, communicated to that large area in directions radiating from the place of entry, relents, and is almost lost, and the sediment which it brought is gradually, and at last wholly, deposited in the lake, whose transparency it disturbs, and the purified stream issues from the lower extremity without a single taint of its stormy origin, *unless it be the colour*, of the mountain-peat, or some other substance held in chemical solution. Like the lake from which it escapes, or the ocean far from shore, it generally assumes the purest ethereal hue, its native tint of green or blue, but soon in its onward course it again becomes turbid with sediment. Every lake in Switzerland exhibits these pleasing effects upon the rivers, which commonly enter in turbid violence, and issue of a lovely transparent green, but the Rhone is pre-eminently blue. These lakes are filling and contracting at their upper ends with the sediment which they filter from the rivers, and the process, though historically slow, is monumentally impressive, since we perceive large tracts of level meadows cultivated, covered with trees, and adorned by ancient and modern towns, where formerly flowed the deep waters of the lake.

All this *new land* was formed from the spoils and waste of the upper countries drained by the river, and it is an exact measure of the whole effect of the atmospheric and local influences in weathering the face of the hills, and of the rivers in transporting away the materials thus prepared for them *from the earliest period when the streams began to flow* down the actual valley.

Arrangement of Materials.—The second thing to be attended to in considering the effects of lakes on the line of rivers, is the arrangement of the materials which they receive. This is a subject in which

Mr. Yates's observations* will be found useful. It is known to practical men that loose earth will remain at rest if it be placed at an angle, not exceeding 45° with the horizon, and when loose, earthy materials are poured from a height, they usually arrange themselves in a conical heap, whose sides make nearly this angle with the horizon. On the slopes of mountains liable to avalanches or rapid waste, the loose debris is usually found in a plane declining at about this angle. When streams falling over an edge, pour with their waters a quantity of earthy matter, the conical heap so produced is very much more obtuse than when the materials fall dry, and the larger the proportion of water that comes down, and the more forcibly it descends, the flatter is the slope of the cone. This will easily be understood upon the principle that by partial suspension in water each particle is influenced by the tendency of that fluid to become level.

It is easy to understand from this that the form in which coarse sediment will be deposited by rivers entering a lake, must be in a very obtuse cone radiating round the point of entrance. As the heap of sediment is advanced into the lake by continual additions, its outline remains circular, with a larger radius, and its section will be nearly level toward the land, but sloping more and more rapidly toward the interior of the lake. Were the particles to be arranged in obedience to the double forces of horizontal movement with the river, and of perpendicular descent from gravitation, the curve of the edge would be parabolic, and the surface left upon the sediment toward the land nearly level.

But the earthy matter being unable to support itself at more than a certain angle of elevation, the lower part of the curve will become less steep, and be reduced to a straight line. Mr. Yates's observations on the Swiss lakes led him to assign to the sediment left therein an outline of this kind.

It is obvious that in these cases the sloping layers nearest the entrance of the stream are of older date than those farther advanced into the lake. It is an interesting subject of inquiry to learn whether, as is most probable, the particles of the sediment which differ in bulk and specific gravity, are arranged according to those qualities so as to constitute horizontal strata, of finer and coarser matter, &c.; and whether, this being the case, the sloping lines of deposition, &c. are visible or obliterated in the section. In this manner the upper ends of lakes are filled with the deposits from the rivers almost to the surface; and, the dams of the lower ends of the lakes being worn away by the incessant action of the stream, these deposits become visible above the water, and constitute those smoothly declining, often moist surfaces, which usually confine within their indefinite border the

* Edinburgh Journal, 1831.

shallow and weedy waters destined in their turn to retreat from the desiccated land. While this process proceeds near the shore with the coarser particles, it is obvious that the finer sediment will be carried farther into the lake, and be spread more widely over its general bed.

These remarks apply only to deep lakes, whose waters rest tranquilly on their beds, and are only agitated at the surface. In shallow lakes, which are agitated to the bottom, the materials must necessarily be distributed in planes very nearly horizontal, in consequence of the impressions from the fluctuations of the surface. This is matter of daily observation.

Lacustrine Deposits.—Before we dismiss the subject of lakes, it will be proper to take notice of another process tending also to fill them with new deposits. Many streams which enter lakes carry along, dissolved in their waters, a quantity of carbonate of lime, which may afterwards, by the loss of carbonic acid from the water, fall in calcareous sediment, and constitute beds of marl, or by the slow absorption of mollusca be converted to shells. In the latter case, beds of limnææ, paludinæ, &c. are formed, and as, generally, the light argillaceous sediment entering such lakes is pretty equally diffused through the waters, the result is a bed of marly clay full of fresh water shells. This process is daily going on, and in the course of a few years canals and river courses, as well as ditches and ponds, are choked by the abundant accumulation. In this manner, aided by occasional inundations, bringing layers of vegetable matter, or the detritus of the neighbouring country, have many old lakes become entirely filled up, and when cut open for any purpose, present layers of peat, clay, shell, marl, and sand, a faithful image, on a small scale, of those great fresh water deposits which mark the force and extent of ancient currents on the surface of the earth.

Deltas.—The delivery of the sediment of rivers into quiet, tideless, land-locked seas is almost perfectly analogous to what happens in a large lake, but according to variation of circumstances, as the river flows into the open ocean, and contends with strong tides and sweeping currents, or disembogues itself into a gulf, enters deep or shallow water, the disposition of its sediment is different. The most remarkable deltas at the mouths of rivers are formed round such as empty themselves into tideless seas, as the Mediterranean, Black Sea, Caspian, Baltic, &c., or into comparatively quiet bays of the ocean, as the Bay of Bengal, the Gulf of Mexico; and the least effects of this nature are occasioned on coasts which are subject to be raked by lateral currents of the sea.

Most of the great rivers which enter the Mediterranean are daily increasing their deposits along the coasts, and spreading a quantity of sediment over the general bed of the sea. The Mediterranean

has been proved by a line of soundings on the Skerki shoal from the African to the Sicilian coast, varying unequally from 7 to 91 fathoms, to be divided into two basins. In the western portion, near Gibraltar, the bottom, consisting of sand and shells, has been reached at 5,880 feet, and in the straits at 4,200 feet. Almost under the shore at Nice the depth is 2,000 feet; but in the Adriatic, where it receives the sediment of the Po and other rivers, in the upper part, the greatest depth is 22 fathoms. Yet from the abrupt borders of the hill ground within the area of the sedimentary land, it is inferred that the Adriatic must formerly have been a deep gulf.

Nature of the Deposits in Gulfs, Estuaries, &c.—Farther from the influence of the rivers the depth increases considerably. Donati, on dredging the bottom of the shallow portion of the Adriatic, found it to consist partly of mud, and partly of calcareous rock, enclosing shells, which are sometimes grouped in families. (Lyell.) The form of these sedimentary deposits must be what in common language is called horizontal, the substance of them fine clay and calcareous matter with shells; and as the ratio of accumulation is nearly uniform, there will be little appearance of strata, unless the calcareous deposits be accomplished at intervals. If by any effort of subterranean forces this bed of the Adriatic should hereafter be elevated and made dry land, as so many other extensive tracts along the borders of the Mediterranean have been, we should have an argillaceous deposit extremely similar to the London clay, and perhaps identical with the subapennine marls, except by some difference of organic remains, and of such an extent as would appear incredible to those who believe in the almost quiet slumber in modern times of the mechanical and chemical forces which belong to our globe. The same conclusions might be derived from an examination of the mouths of the Rhone, Volga, Danube, Ganges, Euphrates, &c., which enter the sea under the same favourable circumstances, and transport enormous quantities of fine sediment into comparatively tranquil and now shallow waters. A river like the Mississippi, which hurries an enormous volume of deep waters, and preserves its velocity to the edge of the sea, discharges likewise a prodigious quantity of matter, which settles round its many mouths into a vast and growing delta. But the kind of matter here deposited and the mode of its arrangement will be different. Forests matted together by the growth of ages, with all their foundations, their alligators, and other inhabitants, are swept down by this mighty stream, and either retarded for a time among its winding and variable channels, or hurried into the sea, and there, with quantities of similar matter, agitated, and partially or completely separated into beds of earthy and vegetable matter, the latter varying according to the prevalence of the many rivers which unite in the great stream, and thus the

gulf of Mexico is now filling with deposits, which in no feeble degree emulate our old carboniferous strata. We are informed by Lyell, whose volumes are full of valuable information on all subjects connected with the modern operations of natural agencies, that a great part of the new deposit at the mouth of the Rhone consists of calcareous and arenaceo-calcareous rock, containing broken shells of existing species; and Captain Smyth ascertained that over the broad, very gently inclined bed of this growing delta, marine shells were occasionally drifted by a south-west wind. In this way alternations of fresh water and marine shells may be occasioned, in which the marine portions will predominate towards the sea and the fresh water part be most decided toward the land.

The shorter and more rapid the course of a river, the larger and coarser is the sediment which it may be able to transport. While the Po, relenting in its velocity, leaves its gravel where it joins the Trebia, west of Piacenza, 130 miles from the sea; and the Ganges 180 miles above the commencement of its delta, and 400 miles above the present line of coast; the rough bed of the Yorkshire Tees is pebbly quite down to the sea; and the streams which descend by a short and furious course from the Maritime Alps bear down pebbles into the Mediterranean.

From these instructive examples of pebbly, sandy, argillaceous, and calcareous strata, forming at the same era, in different basins of the sea, and even in different parts of the same basin, enveloping entirely marine, entirely fresh water, or a mixture of marine and fresh water deposits, we may turn with advantage and pleasure to the contemplation of the older strata of conglomerate, sandstone, clay, marl, and limestone, and, by carefully noting the points of agreement and circumstances of difference, may frame very satisfactory notions of the conditions under which they were deposited respectively. Especially we may be guided in our decision concerning the extent and connection or separation of the several basins of the ancient ocean, and the relative influence of ancient and modern rivers.

Bars at the Mouths of Rivers.—Rivers which discharge themselves into the sea, where tides and currents contend with the freshes, may, as the Rhine, be enabled for a certain time to deposit their sediment in a delta, and to increase this even to a vast degree, in consequence of their entering at a deep emargination of the coast, or amidst shallow sands which impede the action of the tide. But in such a case the accretion of land must gradually diminish, and at length the movements of the sea must balance the current of the river. In this case a line of sand-banks will be formed varying in position according to the alternate predominance of the contending forces, and the entrance of the river will have a bar. The Rhine, the Thames, and all the eastern rivers of England are nearly in the same case. The

sea, indeed, has again reclaimed from the Rhine, by most destructive floods, the large spaces of the Zuyder Zee and the Bies Boos.

Thus also the growth of the Nilotic delta, once so rapid, is greatly retarded or almost annihilated by a current of the Mediterranean; and the rivers of western Africa, as well as the mighty Maranon, no longer extend themselves into the sea, but meet its currents in furious strife, drop the sand at their mouths, and resign their finer sediment to the disposal of the conqueror. The distance to which the ocean can waft this sediment on its surface along with fresh water is very great. Colonel Sabine supposes himself to have crossed the discoloured waters of the Maranon 300 miles from its mouth, where it still retained its comparative levity, and kept its place on the surface of the sea.

Thus may the sediments of distant countries be mixed or alternately deposited far from shore, and even in the deep sea, a fact of great interest to geology. The distinctness of currents of water which flow down the same river channel, even with a rapid descent, has often been noticed. Thus the Arve and the Rhone flow far without mixing, the Nahe takes one side of the Rhine, and even in the mining districts of England, the discoloured streams from the different valleys can often be distinguished along considerable lengths of the united river.

We shall not further extend our remarks on this subject than by stating a few instances of the actual surface of the deltas of great rivers. The whole area of the dry delta of the Po and the Adige, and other rivers which contribute to the effect on the same line of coast, must exceed 2,000 square miles, and within the last 2,000 years a space of 100 miles in length, and from 2 to 20 miles in breadth, has been added to the land. The area of the Nilotic delta is about 12,000 miles, and according to Girard the surface of Upper Egypt has been raised by the sediment since the Christian era 6 feet 4 inches; of the Rhone 1,500 square miles; of the Quorra 25,000 square miles.*

The delta of the Ganges, without reckoning that of the Burampootra, which has now become conterminous, is considerably more than double that of the Nile, and its head commences at a distance of 220 miles in a direct line from the sea. The base of this magnificent delta is 200 miles in length.†

The fen lands of Lincolnshire, Huntingdonshire, and Cambridgeshire occupy 1,000 square miles, and the levels in connection with the Humber 300 or 400.

It has been attempted to deduce the age of our continents from the rate of increase of the deltas of rivers within the historic era. Thus

* Dr. Fitton, Geology of Hastings. † Lyell.

the Nile was supposed by Herodotus to have formed Lower Egypt; and he states that if diverted into the Red Sea, it would fill that gulf with its deposits in less than 20,000, or even 10,000 years. Since the time of Herodotus it is supposed that the increase on the Nilotic delta has been upon an average, one mile and a quarter. The average annual growth of the delta of the Po, opposite Adria, which was once on the edge of the Adriatic, was, from 1200 to 1600 A.C., 25 metres, and from 1600 to 1800, 70 metres; a very rapid increase of rate, probably connected with the increasing shallowness of the sea.

But all inferences from observations of this nature, and similar ones on the shallowing and conversion to land of the upper ends of lakes, can lead only to merely speculative results without the knowledge of a datum very difficult to be obtained, *viz.* the original depth of the sea or lake, at all points over which the river sediment has flowed; for it is not by the *area* of the delta, but by the *cubic content* of the sediment transported that the time occupied in the process is to be ascertained. How is this to be determined?

The Sea.—As the action of rivers is of two kinds, erosive and transporting, so is that of the sea. In one place its fury excavates the cliffs, and devours a whole country, in another every tide adds sediment to a growing shore, lengthens the fields, and extends the parishes, till what was once a broad bay becomes a fertile marsh, and the town which was once a flourishing port is far removed from the waves, and never visited by commerce. These different effects depend principally upon the circumstances under which the earthy materials are presented to the waters. Cliffs exposed to the sea are either slowly decomposed by its vapours, and crumble piece-meal, or undermined at the base, and so caused to fall in ruinous heaps. Even the hardest rocks that begird the ocean are more or less wasted away by its never-ceasing attacks, conjoined with the common atmospherical agents. Soft places are scooped into caverns, joints are widened, and blocks loosened, and thus, by little and little, every high coast recedes and yields more or less ground to the insatiable waves. But cliffs composed alternately of softer and harder strata, especially if there be any dislocation, are quickly eaten away, and still more rapid destruction falls annually on the crumbling diluvial clays and loose gravelly cliffs which margin so great an extent of the coast of England. The whole of the English coast may be cited for cases of this important wasting of the cliffs, and in particular the diluvial cliffs of Yorkshire and Norfolk. In the former county it seems to be ascertained, by careful measurements at many points, repeated after intervals of many years, that the annual loss of land

* Lyell, Principles of Geology.

on the whole length of Holderness, is not less than $2\frac{1}{4}$ yards in breadth annually. The average loss on the coast of Norfolk between Weyburn and Theringham is about 1 yard per annum, on the coast of Thanet 2 or 3 feet. But these same coasts likewise exhibit, on an equally grand scale, the formation of *new land* from the materials thus detached from the old. The materials which fall from the cliffs are sorted by the tide, and according to their bulk and weight are differently disposed of. As in many artificial processes of washing powders the sediment is divided into parts of different fineness by merely shaking it at different distances or depths in the stream of water, so it is in the great currents of the sea. Large stones remain a long time at the foot of the cliff from which they fell, smaller masses yield something to the impetus of the waters, sand and pebbles are drifted along the shore according to the set of the tide, and collected into bays and hollows of the coast, or deposited in a line of moving beach; but the finer clays are transported far away in the waters, and allowed to settle only where these rest in land-locked gulfs, stagnate over weedy marshes, or lose their force in contest with the freshes. The breadth of the sandy beaches thus accumulated is often very great, even many miles of slow and regular descent. The sand banks which stretch out so far from the low coasts are often regarded as remains of ancient lands overwhelmed by the sea, but in most cases they are probably recent formations, accumulated by the waves from the spoils of other regions. But what is thus left by the sea under some circumstances, may be again reclaimed by it under others. The once fertile district called North Friesland, most probably accumulated by the sea, measuring from nine to eleven geographical miles from north to south, and six to eight from east to west, was in 1240 entirely severed from the continent, and in part overwhelmed. The island of Northstrand, thus formed, was, towards the end of the 16th century, only four geographical miles in circumference, but still was richly cultivated and populous. At last, in 1634, in one night, the 11th of October, a flood passed over the whole island, whereby one thousand three hundred houses, with many churches, were lost, fifty thousand head of cattle and above six thousand men perished. Three small isles alone remain, and they are still farther wasting. (Lyell.) It may often be remarked that substances thrown into the sea are not carried down at once to its depths, but rejected many times to the shore, in the direction of the tidal currents. This happens especially with all light, small, and easily moved bodies; but the case is different with the large blocks of stone, which, continually pressing by their weight downwards, are for the most part gradually withdrawn from the base of the cliff sunk in the beach, and rolled down to the deep.

In this manner, when the circumstances admit of it, the whole

coast is in motion, every high cliff wastes away, the low grounds stretch out, the beach widens and again contracts, shifts upwards and downwards, and travels along, and thus amidst the extremes of constant fluctuation and change, new deposits are continually added to the quiet depths of the sea, and to the lowest parts of the land. As far out as the fluctuations of the waves can influence the bottom of the sea, the new deposits, where uninfluenced by currents, must become nearly horizontal; in greater depths it seems reasonable to suppose that the materials will be arranged nearly as in deep lakes; and under the cliffs, the beach being only at intervals exposed to the rush of ascending and descending waves, must have its surface inclined at corresponding angles.

347 Gibraltar.

We have no accurate data on which to found an opinion concerning the utmost depth to which the influence of the superficial undulations of water may extend. The influence of the tidal and other *currents* of the sea must extend to a great depth, and tend to equalize into nearly horizontal strata the loose materials collected from the waste of the land.

Coral Islands, &c.—These extensive deposits of sand and clay are, however, not the whole of the productions of the sea. The ocean indeed is but a large lake, and, besides the mechanical effects on its borders, is subject to various chemical changes, and to the unceasing agency of the functions of organic beings. Into that vast repository there flow annually great quantities of soluble matter of various kinds, and it is quite conceivable that by the interchange of their elements some chemical deposits may happen. It is also not unreasonable to

admit that many exhalations rising from the bed of the sea may co-operate in such effects. But there is one ascertained cause incessantly in operation which probably occasions more extensive and permanent precipitation of carbonate of lime than any other process—the growth of zoophyta, shells, and crustacea. However small may be the quantity of calcareous matter suspended in water, the molluscous and zoophytic animals, which require such matter for their stony supports, are sure to possess themselves of it; and as corals and shells remain when their tenants dissolve away in the water, the bed of the sea is continually receiving important additions from this source alone. Besides these, the cast shells of crustacea, the teeth, and sometimes the skeletons of fishes and cetacea, must contribute no mean quota to the growing stock. It is perhaps yet an undetermined question to what depths in the sea light and the vital influence of the atmosphere can sustain the growth of plants and animals. We may, however, safely believe that the extreme gulfs of the sea are as devoid of organic life as the central solitudes of a sandy desert, while the borders of the one, and the shores of the other, teem with innumerable forms of life.

It was formerly supposed that those immense reefs of coral which divide the waters of the Pacific Ocean, and rear themselves above the waves into associated islands, arose from the deepest parts of the sea, in perpendicular walls. But many observations by Captain Beechey, Darwin, Stutchbury, and other navigators, upon the crater form which the coral islands generally assume, and the volcanic rocks upon which they are frequently based, have produced a very general impression that these polypean races do not exist except at moderate depths. Captain Beechey found the coral of Ducies Island to be forming at a depth of one hundred and eighty feet; the reef-making madrepores are seldom found below 100 feet.

The quantity of carbonate of lime thus produced by the coral animals, with the addition of shells, &c. enveloped by them in their progress, is really enormous, and might almost justify those geologists who think that our stratified limestones are wholly derived from comminuted shells and zoophytes. A great proportion of all the low islands in the South Pacific Ocean is the work of zoophytes, and new islands are daily in progress, and submarine reefs of so great extent, that Captain King found a continued line of coral reef 700 miles in length, from the north-east coast of Australia towards New Guinea. It was interrupted only by a few intervals not exceeding in the whole 30 miles in length. These reefs consist in great part of compact limestone, and Lyell compares them to the ancient calcareous rocks of the basins of Europe and North America.

This comparison, so just as to quantity of material, must not be extended to the structure and arrangement of the several masses.

The rocks of carboniferous limestone have indeed derived a large part of their materials from the calcareous secretions of polypean and molluscous animals; but the materials can have been put into their present stratified form only by the ordinary mechanical action of water upon them. A modern coral reef might, by long movement in water, be ground up into something like a limestone bed; but the sharpness of the angles of the ornamented fossils of all the old calcareous strata appears to disclaim such an origin for these rocks. At the same time it is to be observed that the corals and other zoophytic reliquiæ, which abound in some of our limestones, very seldom appear to be in their ordinary places of growth, but rather seem to have been subject to some slight drifting. The corals may therefore in ancient times have grown in reefs, as at present, and this may perhaps be the reason of their irregular and unequal dispersion in the rocks—a fact particularly remarkable in the coralline oolite. On the whole, the Bermudas afford, as explained by Nelson,* the best general term of comparison between modern coral accumulations and ancient coralline limestones.

* Geological Proceedings, 1834.

348 Needles, from Scratchells Bay.

CHAPTER XVI.

ROCKS PRODUCED BY THE AGENCY OF HEAT.

Below the numerous deposits from water, we discover rocks formerly fluid through heat—crystallizations from igneous fusion. Some of the earlier marine strata are obviously composed of materials derived from still older igneous rocks. Thus granite, after being crystallized, has by subsequent disintegrating processes been separated into its elementary minerals; these at a later time have been again reaggregated, and consolidated into the rock called millstone grit. So with regard to the oldest of the strata, gneiss and mica schist, we believe some of them to be really derivative strata, and to retain traces of their stratification and of their aggregation from separate mineral ingredients, however nearly, by metamorphic agglutination, they may claim to rank among rocks of fusion.

Earlier than all the terraqueous condition of the globe, we infer an igneous condition, and behold a spheroidal fluid mass, whose external figure and interior density were in equilibrio with the rotatory and attractive forces impressed on the mass by its Creator and Director. On this basis we proceed to trace in a few pages those operations of the earth's internal heat, by which some classes of rocks have been upheaved from below; certain alterations have been effected in others; the earth's crust broken and displaced; the level of land and sea altered; the physical condition of the globe modified. These operations are represented in our days by those volcanic disturbances which shake from time to time the solid framework of the earth; raise islands and depress mountains; and pour out, on the surface of the land and the bed of the sea, many streams of melted rock, which are always comparable with the igneous products of earlier date, and sometimes undistinguishable from them. Even as the modern daily operations of water furnish the key to the history of primeval strata, so the occasional violence of volcanos throws open the secret laboratory of nature, and

"Lets in light on Pluto's drear abode."

The order followed by nature in the production of the crystallized rocks of fusion, seldom admits of more than local determination. If we regard them as acquiring solidification by cooling in zones more or less parallel to the surface, we should have granitic and basaltic sheets of rock generated *below*, the first uppermost, the last lowermost; while *above* the several strata were produced in a series beginning at the bottom. In this sense the rocks of fusion may be called, with

Lyell, *hypogene.* Certainly under particular areas of country, we find evidence of the liquefaction of one set of igneous products after the solidification of others. Thus dikes of basalt traversing granite show themselves to have been in fusion after the solidification of granite.

Granitic Rocks.

Various Conditions of the Production of Igneous Rocks.—The circumstances under which the germs of igneous energy may be excited to activity, are so various, that even amongst volcanic products poured into the atmosphere, there is great local diversity. If we remember that, for the most part, the phenomena of submarine volcanic action are wholly concealed from our view, we shall be prepared

349 Granite Peaks, from Lagan Hill (Arran).

to expect that among the masses formerly produced by it beneath the bed of the sea, and uplifted by subsequent convulsions to the day, many varieties of rocks should be met with, differing very greatly from the products of actual volcanos. As the far greater portion of volcanic effects takes place in the deep parts of the earth, where the rocks remain to be again and again exposed to new influences, it is reasonable to suppose that the products collected from volcanic vents form but a small part of the series.

The subterranean lavas, now in course of production and consolidation, could they be uplifted to the day, would be found very different from the superficial lavas, and far more extensive and abun-

dant. Though, as the preceding section has shown, there be many close analogies between ancient and modern igneous rocks, we ought to expect that the most abundant of these old rocks, while they afford sufficient evidence of their being generated by heat, should appear different from ordinary lava. Granitic rocks are exactly in this case; they are more abundant than the trap rocks, which most closely imitate volcanic products, and have a different general character. Yet as between superficial and subterranean lava every variety of products may be expected to occur, corresponding to the various conditions, we find between granitic and basaltic rocks so many intermediate varieties, that it is impossible to separate, by hard and decisive characters, even these extremes of the series of old igneous rocks. Basalt is really a volcanic product, in the restricted sense of the word, though not exclusively so; and thus we have from vesicular pumice and glassy obsidian an uninterrupted series of gradually changing aggregations to granite.

Granite is a most variable rock. Even in limited districts it exhibits itself at detached points, with very different mineral aspect and accompanying phenomena. In Cumbrian districts, for example, the granite north-east of Keswick is composed of white felspar, gray quartz, and black mica; that of Shap Fells has reddish or yellowish felspar, and is largely porphyritic; that of Muncaster Fell, near Ravenglass, is often a binary compound of gray quartz and white felspar, and other varieties abound round Devock Lake.

Rocks allied to Granite.—Granite deviates on the one hand by continual decrease of the magnitude of its particles into very close grained felspathic rocks, which are greatly analogous to certain kinds of porphyry; on the other, by the substitution of hornblende for mica into syenite. As examples of the latter change, we may instance the syenitic granites of Cruachan and Strontian. The former is illustrated in the granite veins of Arran, and in the fine grained granite of Wastdale and Dufton Pike, in Westmoreland. In some cases it might, perhaps, be safely admitted, that the same originally fluid mass has been consolidated partly into granite and partly into porphyry, according to the circumstances in which the lapidification happened. In the Valteline granite deviates into hypersthene rock.

General Argument.—It would be a mere waste of time to repeat, for the particular case of granite, those arguments, derived from the crystalline aggregation of many minerals never known to be produced from water, but several of which have been fabricated in the furnace, and nearly all are volcanic products, which establish the probability of the igneous origin of the whole class of plutonic rocks. We have shown above that the composition of granite passes by very easy steps to that of rocks whose igneous origin is perfectly unquestionable. If to this we add the fact, of granite entering cracks and

fissures in contiguous rocks, as clay slate in Cornwall, hornblende slate in Glen Tilt, gneiss in Cumberland and at Strontian, we shall have said enough in the present advanced state of geology to secure the admission that granite was generated by heat.

The alternations which in several countries obtain between granite and some of the older stratified rocks, as mica schist, gneiss, &c., seem not at all irreconcilable with this view; but they will hereafter, when rightly understood, be found of great value in determining some peculiar conditions of the granitic eruptions.

Peculiar Character of Granite.—If we seek to understand the circumstances which have impressed upon granite characters so generally distinct from those of the other plutonic rocks, we shall find the following facts important:—1. Granitic rocks usually occur in very large masses below the whole, or a very large part of the whole series of strata, and were evidently formed under the pressure of a great body of water, if not under a pile of superincumbent strata. 2. They are so extensively spread beneath the neptunian rocks as to deserve, perhaps more than any other, the title of an universal formation. 3. Granite veins, in proportion to their minuteness and distance from the parent mass, grow continually finer in the grain and more porphyroidal in every respect. This effect is most completely seen along the sides of the veins. 4. In countries where the great masses of igneous rocks are granitic, as for example Cumberland, the dikes and smaller masses are mostly of porphyry, or of a felspathic quartzose rock, of rather dubious character, which may be called syenite, porphyry, or unmicaceous granite, according to the locality. Such rocks occur about Wastdale head, in St. John's Vale, under Helvellyn, and in High Pike.

On comparing these general facts with Mr. G. Watt's experiments on the aggregation of fused basalt, there appears sufficient ground for believing that the very high crystalline character of granite is owing to its being produced at great depths where it was very slowly cooled to the point of crystallization. We may further venture the hypothesis, that much of the rock we call porphyry is merely another state of consolidation of a similar felspathic compound, as trachyte has been supposed to be derived from older porphyries, or even from granite.

Comparison of Ancient and Modern Pyrogenous Rocks.—It appears, therefore, that among the older pyrogenous rocks we may distinguish the same two leading groups as among the modern volcanic products, characterized by the prevalence of some kind of felspar in the first, and of augite, hornblende, hypersthene, diallage, or some other analogous generally ferruginous or magnesian mineral in the second; that in each of these occurs a great variety in the size, distinctness, and aggregation of the crystals, corresponding to the circumstances

of the consolidation and differences of composition of the mass. The following short synopsis will express some of these relations among the older rocks.

Plutonic rocks are:—

1. Felspathic:—as granite, porphyritic granite, porphyry, amygdaloidal porphyry, claystone, pitchstone.
2. Hornblendo-felspathic, Hyperstheno-felspathic, &c.:—as syenite, hypersthene rock, gabbro, serpentine.
3. Hornblendic, hypersthenic, &c.:—as greenstone, basalt, trap porphyry, melaphyre, amygdaloidal trap, wacke.

On reviewing this series, and considering the manner of occurrence of the several members of it, we shall find that the large prismatic structure is perhaps more generally developed in the augitic and hornblendic pyrogenous rocks, than in the felspathic branch, and that in both groups the highly crystallized varieties, as granite, syenite, and greenstone, exhibit less of this remarkable structure than is common to granular claystone and glassy pitchstone, or fine grained basalt and trap porphyry.

Granite Veins.—Another thing worthy of notice, is the circumstance that veins proceeding from the mass of a pyrogenous rock into the small cracks and short fissures of a stratified rock are almost peculiar to granite. This phenomenon is hardly ever noticed along the sides of a *dike* or interposed bed of basalt or porphyry, and is at least very uncommon in connection with even large masses of greenstone. On the contrary, granite is very seldom found in dikes like the augitic and hornblendic rocks, though there is reason to believe that it assumes the form of overlying masses, and alternates in seeming beds with gneiss or mica slate. (S.E. of Ireland.)

This circumstance leads us to suppose that in many of the cases the injection of granite happened not near the surface, or at a time of violent eruption and elevation of strata, but at great distances below the surface, while the strata were sunk into zones of depth so great as to come under the influence of *the earth's interior temperature*.

The variety of interesting considerations connected with granite will justify us in taking a more extended review of its mineral and chemical composition than will be necessary while treating of other pyrogenous rocks. Granitic rocks have long been regarded as the source of most of the ingredients of sedimentary strata; a newer theory supposes that granitic rocks are continually forming beneath our feet, in quantities proportioned to the time, by the action of subterranean heat upon the ordinary strata. On both of these points some further information concerning the composition of granite will be useful.

Felspar.—Granite is essentially a felspathic rock. Whatever variations happen in respect of the quantity of other ingredients, felspar,

in a crystallized state, is universally the basis of granite. In graphic granite the planes of crystallization of the felspar are continuous for great spaces; in porphyritic granite it sometimes happens that the axes of the prismatic crystals of felspar lie nearly in the same direction; but in common granites it is probable that the crystals of felspar lie in all directions, like the calcareous crystals of primary limestone. The felspar is red, white, green, &c.

Felspar is now the title of a family of minerals, and includes several species and varieties. Those most frequent in granites have a large proportion of silica compared to the alumina which they contain. They are, in fact, mostly trisilicates of alumina, with additions of silicate of potash, silicate of soda, or silicates of bases, isomorphous with these respectively.*

Orthoclase, or potash felspar. Adularia, and common felspar, have a low specific gravity (2·5 to 2·6); melt to a porous glass; contain essentially 65·4 silica, 18 alumina, 16·6 potash, and other bases. Symbol $\dddot{Al}\ \dddot{Si}^{3} + \dot{K}\dddot{Si}$.

Albite, less frequent in granite, has a higher specific gravity (2·59 to 2·65), melts more easily; contains essentially 69·3 silica, 19·1 alumina, and 11·6 soda, and other bases. Symbol $\dddot{Al}\ \dddot{Si}^{3} + \dot{Na}\ \dddot{Si}$—differing from orthoclase in the second term only by the substitution of $\dot{Na}$ (soda) for $\dot{K}$ (potash).

Oligoclase occurs in some granites, with a specific gravity of 2·6 to 2·7; melts easily; and contains essentially 63 silica, 23 alumina, and 14 soda, and other bases. Symbol $\dddot{Al}\ \dddot{S}^{2} + \dot{Na}\ \dddot{Si}$.

Quartz.—Quartz, in a gray, transparent state, more or less evidently crystallized, is almost never absent from granite, but its quantity is very unequal. In graphic granite, quartz, in a sort of interrupted crystallization, is engaged among the laminæ of felspar, so as to assume angular and intersecting figures not unlike the characters of some Oriental language. In the porphyritic granite of Westmoreland the natural faces of the large crystals of felspar are impressed with very small bipyramidal crystals of quartz; and in other granites the quartz may generally, with care, be found crystallized in this form, so as to present on a polished face a regular or elongated hexagonal section. There seems also in some granites a portion of uncrystallized quartz, which is entangled among the other ingredients in irregular shapes. Binary granite, of quartz and felspar only, is seldom met with in Great Britain. It forms part of Muncaster Fell in Cumberland.

Mica.—Mica, the third ordinary ingredient in granite, is occasionally very abundant in it; but sometimes absent. It is universally

* See Daubeny on Volcanoes, 2d edition, p. 13.

crystallized, generally in regular hexahedral plain laminæ, which enter or cut into the crystals of felspar and quartz, without being themselves interfered with. The direction of the crystals of mica is indeterminate; they do not occur in continuous laminæ, so as to cause the rock to cleave; for though porphyritic granite is in a certain sense cleavable, this arises from the parallelism of the crystalline axes of the felspar. Yet in some Cornish granites we occasionally see the mica aggregated together in a sort of shell, which gives a notion of some kind of lamination, arising perhaps from a limited intestine movement of the mass.

There are several species and varieties of the family mica. The most common in granite, potash mica, with specific gravity 2·8 to 3·0, is fusible; contains about 44 to 45 silica, 36 alumina, and peroxide of iron, 10 to 14 potash, and other bases, combined with silica, and about 6 water.

Order of Crystallization.—It is generally presumed that the three most common ingredients of granite were crystallized together; by which is meant, that the consolidation of all the crystals was contemporaneous, neither preceding nor following another. This seems not always *exactly* true. In the Portsoy granite, the quartz is impressed by the felspar; in other granites the impressions of the substances are observed in a different order, and the quartz gives its form to the felspar. This, however, is the least common. Spiculæ of schorl often shoot across both quartz and felspar.* In many cases we cannot doubt that mica was crystallized before the other ingredients. If we follow the indications of the penetration of crystalline forms, we shall find in several instances that the figure of the quartz was complete before the felspar was wholly consolidated; and perhaps, adding to this the consideration that the detached crystals of felspar in the solid parts of granite have, in general, only one, and that the primary form of the crystals, or the primary but slightly modified, while quartz and mica invariably appear in secondary forms, we may venture to conclude that such detached felspar in porphyritic granite, was the last crystallized, and, by consequence, has imparted to the mass its most important features. In many large grained granites are cavities, in which free crystallizations of the ingredients occur. In these cases the minerals show themselves in much greater variety of forms, especially the quartz and the felspar. The former assumes variously terminated prismatic forms; the latter is in rhombic prisms variously modified. (Baveno; Arran.)

Contemporaneous Veins.—The aspect of granite is often diversified by the occurrence of what are called contemporaneous veins; a term which is meant to convey the assertion that the difference of

* Playfair, Ill. of Huttonian Theory, p. 320.

character which it marks was coeval with the formation of the rock. In the large grained granite of Arran and Cornwall, the contemporaneous veins usually appear as long, narrow, ramifying portions of finer grain and a different proportion of ingredients ; sometimes with more mica, sometimes with less. The boundaries of these "veins" are indistinct, and the two structures gradually pass into one another.

It will be readily conceived, that a stone composed of crystals so much independent of each other may, especially when the felspar is not very predominant, be very far from solid; it may be very full of minute fissures. These are often clearly enough perceived, sometimes partially filled with small grains of quartz, steatite, felspar, mica, &c. When the stone is by any means subjected to decomposition, the several crystallized ingredients easily separate along these opening cracks.

Embedded Minerals.—It is almost unnecessary to enumerate the various other minerals which are disseminated in granite, except for the purpose of showing how many minerals may be developed from the same fundamental fluid mass. As all of them are *definite* compounds of certain ingredients, and only one simple earthy substance (quartz) remains as a residuum, it is no wonder they are mostly silicates of earthy substances, and that their relative quantity is very unequal, depending upon the possible atomic combinations which should exactly exhaust all the ingredients except the superfluous quartz.

Silicates. Tourmaline, topaz, zircon, cordierite, epidote, garnet, lepidolite, petalite, triphane, steatite, talc, schorl, hypersthene, hornblende, augite, beryl, chrysoberyl, pinite.

Sulphuret of bismuth, sulphuret of molybdenum, tungstate of iron, rutile, oxide of tin, graphite, oxide of iron, &c.

The tourmaline, which is frequently found diffused in crystals, single or grouped through the granite of Dartmoor, is sometimes accumulated in so great a proportion as to exclude the other parts. Hence we not unfrequently find insulated patches of nearly a black colour, and a close grained texture in the midst of a granite, principally composed of large and distinct white crystals and felspar.*

Restricting ourselves to the more common varieties of granite, we may observe, that the difference in the crystallization of the ingredients could not be determined *à priori*, from considerations of the relative fusibility of the minerals; because, in fact, these minerals were all developed from one uniform melted mass, in which the only distinct parts were the elementary substances of silica, alumina, lime, potash, oxide of iron, &c. ; and it would depend chiefly upon the relative cohesive forces and chemical attractions of certain proportions of

* Kidd, Geology, p. 18.

these ingredients what crystals should be first generated. In ternary granite, for example, it may not be that mica and quartz were crystallized before felspar, because this latter is the more fusible substance, but because out of the mingled mass of elementary substances the particular combination which constitutes mica was endowed with the highest attractive energy. Mica might be formed out of a melted mass at a temperature very far below that required for its own fusion; this being separated, there would remain a silicated felspar, from which the excess of silica being separated, it might depend upon the state of the mass as to heat, or some other condition, whether both quartz and felspar should crystallize together with mutual penetration, or one impress the other.

Elementary Composition of Granite.—If we assume granite to consist of 20 parts of potash felspar, 5 parts of quartz, 2 of potash mica, the fused glass from which, on cooling, these minerals were crystallized, must have contained about

Silica	1853	of which	1353	formed felspar and mica, leaving a residuum of 500 silica.
Alumina......	404		404	
Potash.........	282		282	
Lime...........	40		40	
Ox. iron......	44		44	
Ox. mang. ...	3		3	

Had the proportions of alumina and the metallic oxides been greater, it is probable that more mica would have been formed; had they been less, less mica and more felspar might have resulted; and the proportions of the ingredients might have been such that the mica and felspar might be provided with their constituent potash and other parts, hornblende or augite, or hypersthene, with their lime, magnesia, &c., and a residue of quartz remain.

According to the rate of cooling, we might have a large grained or fine grained granite, or a nearly compact rock. If the quantity of felspar was very great, and the cooling rightly proportioned, the mica and quartz might be crystallized in a compact, earthy, or glassy uncrystallized basis. Thus felspar porphyry would be produced from the same ingredients as ordinary granite; and the whole investigation appears to teach us that the mineral characters of pyrogenous rocks depend as much upon the circumstances of their solidification as upon original differences of chemical composition. With this all observations on these rocks fully agree; and it is, therefore, in a right spirit of philosophical generalization that geologists have now accustomed themselves to view the whole series of plutonic and volcanic products as the varied results of one original mode of calorific action operating under a variety of conditions as to cooling, pressure, limitation of space, and other influential circumstances.

Relative Age and characteristic Phenomena of Pyrogenous Rocks.

Age of Plutonic Rocks.—Were, however, our inquiries concerning the relative age of plutonic rocks to be answered only by appeal to observation of the phenomena which they present *in contact with one another*, the research must be abandoned. For they neither show themselves so often in connection, nor display, when in connection, such constant marks of relative antiquity as to permit us to recognize more than one general truth, *viz.* that granite is very often the oldest and basalt very often the youngest of these rocks. But by studying separately the age of each of these rocks in relation to *the strata which adjoin it*, we obtain a more extensive and more exact series of determinations concerning the periods when they have been erupted through the consolidated crust of the earth. The importance of these determinations in inductive geology is so great as to demand a preliminary statement of the mode of reasoning employed in obtaining them.

1. When in any country a certain class of rocks, as for instance the slate rocks, have been convulsed and thrown into new positions before the deposition of another set upon them, as for instance the carboniferous rocks, and we find occupying the axis or nucleus of the dislocation a mass of granite, it is certain that such granite is older than the carboniferous system, because it was uplifted with the older slates. If, in addition, this granite sends veins through the slate rocks so as to prove that it was uplifted in a melted state, we must infer that it is (considered as a solid) of more recent origin than those slates; and, in fact, that the antiquity of its latest fusion is exactly measured by the date of the convulsion.

If there be no veins thrown off from the mass of granite, and no other satisfactory proof of its having been uplifted in a melted state, the age of the igneous rock is indefinable, except by saying that it is older than a given stratified rock. Such a case occurs in the Ord of Caithness. It appears, then, that in any case of convulsion the era of the elevation of the igneous rock is determined by the convulsion, but whether it was actually generated at that time from a melted state, requires other evidence. Now this consolidation from a melted state is what fixes the age of an igneous rock. Granite may, perhaps, have remained melted in the deep parts of the earth through many geological periods, but its age as a rock is counted from the period when its fusion ceased.

2. In Derbyshire the carboniferous limestone is interlaminated for great lengths by an igneous rock (toadstone), which has evidently been poured out at certain intervals by an ancient submarine volcano while the limestone was in formation. The age of such a rock is fixed by the age of the limestone.

3. The basalt of dikes which pass through certain strata, is, of course, not more ancient than the newest strata divided; if at any point the dike should be covered by newer strata which are undisturbed by the dislocation accompanying it, we may generally admit that the basalt is older than these strata. Such a case, perhaps, occurs in those dikes of the Durham coal field, which do not penetrate the magnesian limestone; but it is not always to be affirmed, because the dikes are there often *unaccompanied by dislocation.*

These instances are sufficient to show the truth of two propositions of general application to this subject.

When igneous rocks accompany convulsions, we can always fix the *minimum* of their geological antiquity; when they throw off veins or intrude in the shape of dikes, or interpolated beds, among stratified rocks, we are able to assign the *maximum* of their antiquity.

Guided by these views, and restricting our illustrations as much as possible to the British Isles, we may proceed to describe some of the characteristic phenomena occasioned by the appearance of plutonic rocks, and to fix the eras of their production.

First, we shall notice some of the general features of a district remarkable for the number of these rocks brought into a small compass and presenting diversified effects, and then select instances proper to make known the characters of each.

We shall take an example of the phenomena of pyrogenous rocks in general from that gem of Huttonian geology the justly celebrated Island of Arran, an examination of which may be safely pronounced almost indispensable to a complete geological education.

Arran.

General Features.—The Island of Arran has been very often described, and by eminent geologists. Jameson, MacCulloch, Necker, Murchison, and Sedgwick, Oeynhausen and Von Dechen,* have all written ably on the inexhaustible subject of this little world of geological phenomena; and were it not for a reluctance to add to this weighty literature, other voyagers would be unable to restrain themselves from describing some neglected but curious phenomena. The leading features of Arran are its mountainous and truly Alpine scenery in the northern extremity, and the elevated plateaux of its southern portion. These latter are generally composed of trap rocks, partly syenite, partly porphyry, partly greenstone, with many dikes of greenstone and pitchstone passing through the red sandstone strata

* The short account here given is entirely from the author's personal observations, in 1826. Since the essay was printed, Mr. Ramsay has minutely surveyed the island, and we have borrowed some of the drawings with which, as well as by a beautiful model, he illustrated the structure of this charming island.

which appear around the coasts. The highest northern eminences are granitic mountains forming the nucleus of a great conical elevation of slate rocks, which, overlaid by the red sandstone formation, form a narrow but unequal zone round the granite. The small size of the island, combined with the elevation of the mountains (nearly 3,000 feet), gives to the short glens a very sudden depth, and permits the cliffs to show the great curvatures of strata. Dikes and overlying masses of greenstone, felspathic and trap porphyry, various sorts of claystone and pitchstone, are seen abundantly both on the eastern, western, and southern coasts; and so perfectly are all the phenomena exhibited, that it is difficult to imagine any space of the same limited extent more worthy of being studied for the purpose of understanding the mutual relations of pyrogenous rocks.

350 From the top of Goat Fell (Arran).

That the granite of this island was subject to pressure, while in a melted state, seems sufficiently demonstrated by the fact of its throwing veins through the surrounding slate rocks; this phenomenon may be very well studied at Tornidneon. That the fluid granite speedily acquired solidity in these veins, is a fact which seems to imply *upheaval* to situations where quick cooling was practicable. That its main elevation was subsequent to the deposition of the whole red sandstone system seems also proved by the curvatures which these strata have undergone. This would give for the main

elevation of the granite of Arran a period considerably later than that usually assigned to the principal part of the Highland mountains.

The granite is, as far as can be known, the oldest pyrogenous rock to be seen in the island, for it is traversed by dikes of greenstone and pitchstone, like those which cross the red sandstones. It is observable, however, that these dikes are most numerous at some distance from the granitic centre. At Corygills, at Lamlash, and Tormore, they are exceedingly abundant in the red sandstone, while in the north-eastern face of the island, where that rock is nearer to the granite, fewer dikes appear, and about Loch Ranza the slate is still less divided by them. Perhaps we may venture to add another generalization; *viz.* that these dikes are most abundant beyond the

351 Drumadoon (Arran).

line of violent flexure of the strata from their horizontal position. After measuring with care the directions and breadths, and noting the characters of forty-four dikes, chiefly of greenstone, between Brodick and Lamlash, and also those at Tormore, it did not appear to the writer of this notice that any other dependence of the direction of those dikes upon the local centre of the granitic eruption could be traced.

While in the eastern side of the island, about Corygills, the dikes in the red sandstone are chiefly greenstone and basalt, with a sparing admixture of felspathic and porphyritic claystone and pitchstone, those of Tormore, in light coloured sandstone, are chiefly pitchstone, claystone, and trap porphyry. On both sides occur interposed beds

of pitchstone, divided into columns; on the east are overlying greenstones in rude colonnades; on the west trap porphyry columns; on the east the claystone dikes are highly prismatic; on the west occur many interposed beds, and an arched vein of claystone. The pitchstone of the eastern side is black or green, that of the western coast often variously coloured and graduating to something like hornstone, or to claystone. It is, in one point, at Tormore, of that concretionary structure which reminds us of some kinds of obsidian and sphærulitic traps.

Alterations of Stratified Rocks.—The effects of the pyrogenous rocks upon those in contact with them are less striking in Arran than in many other situations. No new minerals are produced in the slate

352 Granitic ridges, Glen Sannox (Arran).

where the granite touches it, nor in the red sandstones where they are hardened by the greenstone dikes. This hardening is very various in degree, and the causes of these differences are not very evident even upon the examination of many cases. The hardening effect is sometimes communicated to the distance of two or three feet into the neighbouring rock, but generally not to more than a few inches. The hardened parts sometimes stand up in narrow crests. Where dikes cross, it has been found that one of the planes of intersection of the greenstone dikes has been marked by the occurrenee of a very narrow band of black pitchstone. The base of the pitchstone pillars

of the interposed bed in Corygills is softened, where it touches the sandstone below, to a kind of kaolin.

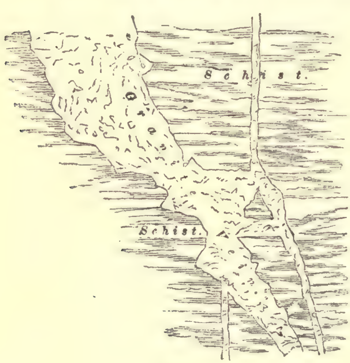
It is impossible to say what was the geological epoch of the later pyrogenous eruptions of Arran, further than that they were posterior to the whole red sandstone system there. If this be correctly taken by Murchison and Sedgwick to represent both the old and new red sandstone systems, they are later than most of those known in England, and, for aught we can tell, they may be as modern as the basaltic eruptions of the north of Ireland.

Geographical Relation of Pyrogenous Rocks.—It is remarkable that, amidst all the profusion of greenstones, pitchstone, claystone, and porphyritic dikes, which appear a little remote from the granite, no granite dike is seen; while in the granite, whose elevation seems to be the local centre of all those exhibitions, no hornblende or augite occurs. That granite and the trap dikes are of different antiquity has been shown before; but it seems also to be implied either, first, that at successive epochs different rocks lay melted under the same localities; second, that the local production of pyrogenous rocks is somehow governed by relations of level or distance, or subject to an obscure reciprocity of position. It seems worth while to follow out this idea. Along the Pennine chain, the axis of dislocation shows, at points, granitic and greenstone rocks, but very few mineral veins are wrought. The slopes a little removed from this mountain edge contain many valuable lead mines. The mining district of Shropshire, described by Murchison, appears related to the greenstone ridge of Corndon nearly in the same way; for though along this axis no mines occur, they abound in a line at a small distance parallel to it. Perhaps to these analogies we may add the instance of the diversified porphyritic masses which run irregularly parallel to, but removed from the granitic axis of Cumbria. Finally, to rise to a greater generalization, Von Buch's views of the relations of the granitic axis of the Alps and the augitic porphyries (melaphyre) along their southern flanks appear to be decidedly analogous, and there seems at least thus much to be inferred from the points of agreement among these several examples of the relative position of ignigenous rocks, that the elevation of an axis or nucleus of granitic rocks was attended or followed by very numerous fissures at a small distance removed, which, after some geological interval, were filled by rocks of a quite different nature from those which were erupted at the time of the first disturbance. A case of this kind occurs in the Malvern hills, where the fusion of the syenite ceased before the earliest recognizable convulsions, and greenstones at a later time passed, melted, through it and several superposed strata.

Antiquity of Granite.—It might be doubtful whether any granite visible in the British islands could claim greater antiquity than the

silurian rocks, except for the cases of alternating granite and mica slate, quoted from Weaver. The granite of the Cornish chain in some places throws veins into the adjacent clay slates, and generally appears to change very greatly the nature of those rocks, so that we are compelled to rank it as a more modern product. The granites of Cumberland and Westmoreland, and those of the Grampians, if their age be judged of from that of the convulsions accompanying them, and from the veins which they throw off, must be pronounced to be of nearly the same antiquity. In the Island of Arran, the granite may not be so old as even the red sandstone which overlies the carboniferous limestone; in the Alps it must perhaps be supposed to have been in fusion even since the tertiary epoch.

Granite Veins.—A few years ago granite veins were considered as rare eruptions, but at present it is difficult to find a satisfactory example of any extensive tract of granite, without the occurrence of such ramifications through the neighbouring rocks. They occur in Cornwall, Cumberland, and Arran, in Ben Cruachan, at Strontian, in Glen Tilt, and generally throughout the Highlands. The same is true for the continent of Europe; and perhaps we may nowhere find a better example of the elevation of granite in *a solid form*, than that described by Murchison at the Ord of Caithness. This granite, on its northern flank, supports the old red conglomerate, whilst to the south it occupies a cliff on and near the shore, the verge of which affords a remarkable breccia, compounded from all the beds of the oolitic series that occur on this coast. This breccia of sandstone, shale, and limestone, is tilted off from the granite wherever that rock protrudes upon the shore, whilst the strata are regularly developed where the granite recedes into the interior. No veins or portions of the granite are to be met with in or above the oolitic breccia, which, by its disturbed position, appears to fix the maximum of antiquity of the elevation of the granite not beyond the age of the coralline oolite.



353

Tornidneon.—The granite veins of Tornidneon in Arran pass from a body of very coarse grained granite through nearly vertical laminæ of dark quartzose clay slate; the line of junction dividing the whole side of a hill (fig. 353). One of the veins encloses fragments

of slate, and divides itself into branches which cross the laminæ of slate, cutting off both the quartzose and argillaceous laminæ. The granite becomes much finer grained along the veins, and nearly in proportion to their smallness; so that in the narrowest veins it is nearly compact. Strings of fine grained granite divide the coarser sort.

Glen Tilt.—In Glen Tilt, MacCulloch has described numerous and valuable facts of this nature. At the bridge beyond Forest Lodge, granite, hornblende slate, and primary limestone are very curiously associated. Veins of red granite here divide the other rocks, and enclose fragments of them. The singular interlacements of the rocks here will be understood by the sketch taken on the spot in 1826.

354

1. Primary limestone laminated by hornblende and red felspar in curved lines or detached masses, round which the laminæ of limestone bend, crossed by granite and red felspar veins.
2. White quartz rock and red felspar crystallized.
3. Felspathic rock, red, with layers of black hornblende.
4. Limestone laminated with felspar.
5. The same with less felspar.
6. Hornblende and felspar in layers.
7. Laminated limestone.

(*a*.) Red felspar vein—a little quartz.

8, 9. Hornblende, with layers, masses, and veins of white quartz, and red felspar, which substances often occur together, making binary granite of very large grain.

10. Limestone, with red granite veins.
11. Limestone, red granite veins, and white *calcareous spar veins, which divide the granite veins.*
12. Red granite, composed of red compact or crystallized felspar, white quartz, and black or gray mica, and encloses hornblende masses which are divided by veins of granite ramifying from the general masses of that rock.

Cornwall.—The extremity of Cornwall has long been famous for the great variety of curious phenomena connected with the granite veins which there divide the argillaceous slate, hornblende slate, and greenstone rocks, all included by the miners under the title of killas. So many writers of eminence, both English and foreign, have described and reasoned upon these occurrences, that it is difficult to select from the immense variety. The following is Majendie's

account of the veins at Mousehole, three miles south-west of Penzance:—"At this period the clay slate ceases, and the granite commences, forming a promontory which runs out in a southern direction from the central ridge. The slate is of a gray colour; it is in strata nearly horizontal, but having a slight dip to the east; it increases in hardness near the junction. The granite, which is generally coarse and porphyritic from the large embedded crystals of felspar, becomes here of a finer grain, with black mica and light flesh-red felspar. On the north it laps over the schistus. At this spot numerous granite veins, varying in width from about a foot to less than an inch, pass through the slate; the two principal veins proceed nearly east from the hill above, for more than fifty yards, until they are lost in the sea. One of these, not far from its first appearance, is divided and heaved several feet by a cross vein consisting of quartz intermingled with slate; fragments of slate appear also in the granite veins. The most remarkable vein, after proceeding vertically for some distance, suddenly forms an angle, and continues in a direction nearly horizontal, having slate above and below." *

The killas at this place has much the aspect of greenstone, and it appears generally true that the clay slate is much altered in character round all the granites of Cornwall and Devon. (See De la Beche's *Geological Map*, *Devon.*) The veins of granite are generally most fine grained towards the walls. Von Oeynhausen and Von Dechen mention three principal veins at Mousehole, one $3\frac{1}{2}$ to 10 feet wide; quartz veins cross the direction of the granite veins, and sometimes divide them, and apparently alter their character. Schorl occurs irregularly in the granite, and in some of the quartz veins. In other localities, veins of this mineral present interesting phenomena. The intricate character of the venigenous masses of Mousehole will be best understood by consulting the diagram, copied from the sketch (fig. 355) of the distinguished Prussian geologist above named.

355

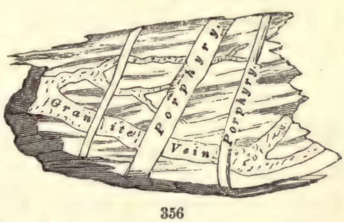
At Cape Cornwall, a granite vein *heaves* a quartz vein in a direction contrary to the general law, stated in page 34. In the Lizard district granite veins divide serpentine.

* Cornwall Geol. Soc. Trans., vol. i.

Felspar Porphyry.

Ben Nevis.—The abundance and variety of felspar porphyry, in great masses on the summit of Ben Nevis, and in the awful valley of Glen Coe, is familiar to every traveller in the Highlands. The porphyry of Ben Nevis has been shown by Von Oeynhausen and Von Dechen to have been erupted through the granitic basis of that mountain. The diversified porphyries along the vertical precipices of Glen Coe send veins through the subjacent granites, in number proportioned to the proximity of the situation to the great mass of porphyry. This rock is not columnar (MacCulloch). It varies through every stage, from claystone to felspar porphyry, the different varieties being sometimes gradually and sometimes suddenly connected. Breccia, composed of fragmented claystones and porphyries (like those on Ben Nevis, and some in Cumberland), are often seen in Glen Coe.

In the mountain of Cruachan, which overlooks Loch Awe, the hornblendic granite and schist rocks are traversed by a great variety of large felspar and trap porphyry dikes, and some changes of appearance happen to the clay and mica slate, very difficult to be described. MacCulloch * describes the porphyry dikes as perpendicular, varying from 3 to 50 feet in breadth, traversing alike the schist and the granite veins which divide it, but not in any degree intermingling with either. Dikes of porphyry, of different kinds and colours, may run near or in contact with each other; but in all cases these and other dikes of basalt or trap porphyry are very distinct at the edges, though firmly united to the rock which encloses them. Fig. 356 shows veins of granite traversing the schist of Cruachan, themselves crossed by dikes of two kinds of porphyry.†



356

Cumbrian Mountains.—In the Cumbrian mountains felspar porphyries occur in many situations, and with a great diversity of character. Some have a basis of translucent gray or green felspar, and included crystals of glassy felspar and quartz; others are composed of a red, opaque, granular felspar basis, and red felspar and quartz crystals; the basis of others is compact felspar or hornstone, and some have a dark but not basaltic base, with small white opaque felspar crystals. Most of them, like the amygdaloids and greenstones

* Geol. Trans., iv.

† Ibid, iv., pl. vi

of the same region, occur in overlying masses as well as dikes, but real alternations of them with the slates can hardly be substantiated. They seem to have a geographical dependence on the foci of granitic eruption of a peculiar kind. They are not abundant in or *very* near to the granite of Wastdale, Skiddaw, or Shapp, but they occur at small distances from each of those masses. The Valley of St. John's shows pale red felspar porphyry overlying slate, well crystallized red porphyry in Armboth Fell, and various kinds of felspathic rocks under Helvellyn. Dikes of variable greenish porphyry divide the slates of High Pike, and a solitary red dike ranges east and west of the granite of Shap Fells. No porphyry occurs very far from the granites.

In North Wales felspathic porphyries appear so connected by alternate bedding with the slates, as to have been subjected to the same elevations and undulations of dip; and thus not only prove their high antiquity, but also suggest views as to the frequent recurrence of igneous action at the same points of the ancient bed of the sea during the period of the primary slates.

Cornwall.—Consistently with our views of the origin of the crystallized rocks, we may, perhaps, be right in believing that all the complicated, wholly or partially, crystallized rocks, composed of felspar, quartz, and mica, which are included between and which traverse the real slaty rocks of Cornwall, are either the result of submarine eruptions during the formation of the slate; of the subsequent action of the heated granitic masses upon the killas; of posterior eruptions of melted rock into fissures caused by convulsion, or of some gradual conversion and transfer of mineral ingredients, such as we know to have occurred.

It is hazardous to reason on phenomena so remarkable as those of Cornwall without reference to other districts. Nothing but prejudice or indolence will permit geologists, acquainted with other districts, to neglect the singular and curious facts connected with the Devonshire and Cornish chain. We may freely admit that they, in some cases, point to agencies not yet familiar to our philosophy; that a full examination of the whole series of granites, porphyries, serpentines, and killas, and of the disseminated and venigenous minerals in them, will kindle a brilliant light in the most secret laboratory of nature; but one thing is wanting, an exact description of *all the characteristic facts observable in each particular case*, without the adornment of theory or the disarray of new nomenclature. Mr. Henwood's volume includes a large and valuable series of observations on the mineral veins. See also Conybeare, Buckland, and Sedgwick, *Geol. Trans.*; the *Trans. of Cornish Geol. Soc.*; the work of Dr. Boase.

Syenite.

Hornblende, the mineral which in syenite wholly or principally replaces mica, has a composition equally variable, often reducible to such a formula as $\dot{R}\,\dddot{Si} + \dot{R}^3\,\dddot{Si}^2$ where $\dot{R}$ is generally lime, but sometimes protoxide of iron or soda, and $\dot{R}^3$ is generally magnesia, but sometimes protoxide of iron. It contains about 41 silica, lime 14, oxide of iron 15, alumina 16, and magnesia 14; easily fusible.

Malvern.—The Malvern hills, long since described with much ability by Horner, and more recently investigated by Murchison,* whose steps were followed by the author of these pages,† will serve to illustrate the phenomena attending syenitic extrusions.

The picturesque chain of the Malverns rises at its centre to 1,444 feet above the sea, and looks down over a vast and beautiful region. On the eastern side the descent is abrupt to plains of horizontal new red sandstone, on the western more gradual and diversified by ranges of woody palæozoic hills whose bearing is parallel to that of the chain. Beyond are the coeval mountains of Wales. Many small narrow valleys descend to the east across the steep slope of the hills.

The verdant surface of these hills, and the circumstance that the pyrogenous rocks are very much decomposed and fissured near the surface, prevents very frequent observation. The great mass of the rocks is of a syenitic rather than granitic character, varying, however, much as to the relative proportions of felspar, hornblende, mica, and quartz. We may collect masses of true granite, and binary granite, true syenite and rocks not separable from greenstones, slaty hornblende rocks, serpentinous rocks, epidotic compounds, compact felspars, and many other segregated varieties. The felspar varies in tint from white to a fine red, and in crystallization from the finest grain to the broadest adularian lamination. Mica lies scattered in broad plates with quartz, or occurs in a massive vein. Chlorite forms a vein. Epidote covers fissured surfaces. There is no known metallic ore of value. Veins of granite are frequent as segregations, and traverse the oldest metamorphic masses, some of which are characteristic gneiss with flexuous laminæ. Veins of sulphate of barytes, calcareous spar, and epidote, red hæmatite, &c., occur in the syenitic rocks. Graphite has recently been discovered, in the railway tunnel, by Mr. Burrow.

Elevation of Strata.—The stratified rocks which are dislocated along the line of the Malverns are best seen on the western slopes, the oldest of them are fucoid sandstones, with a somewhat volcanic aspect; oleni and agnosti appear in black shales above: then

* Silurian System. 1837.

† Memoirs of Geol. Survey, ii. 1.

follow fossiliferous sandstones, considered to be Caradoc beds by Murchison, but regarded as belonging to a higher group by Sedgwick. Into none of these beds does the syenite throw any veins. They rest upon it unconformedly. One of the upper beds of the series, somewhat below the Woolhope limestone, is of a brecciated character, and contains *fragments* of the syenite, mixed with abundance of organic remains, chiefly of the earliest Wenloch (upper silurian) age. Thus it is apparent that the fusion of the syenite of Malvern ceased before the accumulation of the lower palæozoic in that area; that the igneous rock furnished materials to silurian conglomerates, and was upheaved with them at a much later period, in a solid form. The sandstones, limestones, and shales are partly vertical, or partly *overthrown* to the west, so that for some distance to the west the series of strata *appears inverted*, and the really newer rocks come out from under the older.* Much local confusion and disturbance of declinations accompany these general indications of violent upward heaving along the axis of the chain. Horner's very judicious reflections on the bearing of the phenomena of the Malvern upon the then prevalent discussion of the Wernerian and Huttonian theories of geology, will be perused with great satisfaction and pleasure as anticipating many of the clearest arguments known in the present advanced state of the science. As the unstratified rocks have been thrown up along a line from north to south, the bearing of the elevated strata ought, in general, to be parallel to that line, and this has been shown to be the case: the force would be greatest at the point where the unstratified rocks burst forth, and accordingly we find the strata there generally vertical, or even thrown back and in some degree inverted. The eastern boundary of the Malvern is a great fault, throwing down to the east enormously.

The same phenomena of inverted strata were observed by Murchison parallel to the Abberley hills, which are on the prolongation of the Malverns; and we are indebted to him for an interesting notice of a dike of dark green syenitic rock, at Brockhill near the Teme, composed of hornblende, felspar, and quartz, eight paces wide, directed west 5° north, and east 5° south. The syenitic rock is prismatic at the sides, the prisms lying across the dike, whose walls are formed of old red sandstone, here of a green tinge, and marls. In contact with the dike and for 20 feet distance the sandstone is hardened, is of a deep purple colour, and has lost its mica; the marls are altered by the diffusion of carbonate of lime through their mass. I found in these altered strata new *vertical structures*—cleavage on a broad scale —replacing the almost obliterated horizontal strata.† This dike is considered as a lateral effect from the great north and south axis of

* Horner, Geol. Trans., vol i., confirmed by all subsequent observers.
† Memoirs of Geol. Survey, vol. ii., part 1.

igneous rocks of the Malvern and Abberley hills. In the south-western part of the Malvern region, we find several felspathic and greenstone masses, and some dikes, dividing the lowest palæozoic strata, and overspreading in places the black shales with oleni. The shales are usually bleached, and the sandstones partially baked, by this really volcanic eruption, whose date is earlier than the Brockhill dike, but posterior to the solidification of the syenite. The upheaval of the Malvern chain followed the era of the coal formation. The same limits of age must be assigned to the similar rocks of Charnwood forest, which appear under very analogous circumstances. The partially syenitic rocks of Carrock Fell in Cumberland, may, very probably, be older. The variable rock of Red Pike and Scale Force is usually called syenite: according to Weiss, the syenite of Weinbola near Meissen is superimposed on the green sand system.

Hypersthene Rock or Hypersthenic Syenite.

Hypersthene rock forms the pinnacled mountains of Cuchullin, part of Carrock Fell in Cumberland, certain dikes in Radnorshire, and is not unknown in Cornwall; it also occurs in Yorkshire in veins passing through the basalt of the carboniferous limestone series in Teesdale. The exhibition of hypersthene rocks in the Valteline has been described by M. Necker.

This rock may be very generally described as a syenite, of which the felspar is pale flesh-colour, white, or greenish, and the hornblende is replaced by hypersthene, either in very distinct, large crystals, or small concretionary masses. In the latter case it can hardly be distinguished from common greenstone. Murchison finds considerable metamorphic action from the hypersthene of Radnorshire—obliteration of shells in limestone, and generation of serpentine. In Yorkshire it is contemporaneous with the great basalt formation of the carboniferous epoch; in the Isle of Skye it is probably more recent than the oolitic era; in the Alps it forms a part of the mineralogical axis, and may have been thrown up even since almost the whole tertiary strata of the basins of Europe.

The Valteline.—M. Necker, in his account of the Valteline, establishes the fact, that the granitic eminences which rise along the axis of that singular *valley of elevation*, pass by degrees to common syenite, and afterwards to syenite with hypersthene, in large, small, or even minute crystals, of black or green colour, and metallic reflections. The felspar has a violet tinge. The greater and hypersthenic axis of the valley is coincident with the central line of the great chain of the Alps, from south-west to north-east, and the stratified rocks are vertical on each side, for some distance; afterwards they take opposite dips to the north-west and south-east. The

order of succession may be stated to be gneiss, mica schist, changing to talcose and chloritic schist and clay slate. Veins of fine grained granite pass through the hypersthenic rocks and through the mica schist, sometimes holding fragments of this latter, and quartz veins with black tourmalines divide the granite.

Skye.—The Cuchullin mountains in Skye, rendered classical by MacCulloch's descriptions, and Forbes's subsequent survey, surround the desolate lake of Coruisk, a grand amphitheatre of steep and barren rocks, which decompose so little as to yield neither sand nor gravel to the torrents. A great variety of appearances is presented by the mixture of the felspar and hypersthene in these rocks, as to crystallization and colour. In some localities the mass is fine grained, and in others graduates to common syenite or greenstone. Von Oeynhausen and Von Dechen state that the hypersthene rocks pass into compact greenstone; and that the common syenite lies on the hypersthene rock, with an abrupt and distinct junction. One of the most interesting facts connected with this group of rocks is the transmutation of the lias into white granular and compact limestone, where it is in contact with the syenite and trap rocks. This effect happens more constantly at the junction of the lias with syenite than with greenstone or trap; in the latter case it sometimes happens, sometimes not. The hypersthene rock seldom adjoins the lias; where it does, like greenstone or trap, it both intersects and covers it.

Gabbro, Granitone, Euphotide, Diallage Rock, Serpentine.

It is to M. Von Buch that we are indebted for pointing out the importance of the rock, composed of saussurite, or felspar and diallage, called gabbro, or granitone, in Northern Italy. The abundance of serpentine in the Pyrenees, Apennines, and other parts of the south of Europe, has long been remarked. Diallage rocks are equally abundant, often occur in connection with the serpentine, and there is now no doubt as to the fact that these two rocks are very intimately related. Few conclusions of this nature appear better authenticated by observation than the gradation of diallage rock into serpentine, in the Alps, the Apennines, Corsica, and Cornwall. Gabbro has been employed in architecture by the Romans, and by the family of Medicis at Florence.

Stratification of Serpentine.—Generally observers agree in representing both gabbro and serpentine as unstratified rocks. When portions of them are included between strata of gneiss, mica schist, &c., they may be viewed as interposed masses. But MacCulloch positively affirms that in Unst the stratification, both of diallage rock and of serpentine, is certainly evident; and he compares the cases where no stratification can be traced in the latter to analogous

instances in primary limestone. The latter, however, is by far the most abundant case; and perhaps, taking into account the circumstance that in Unst the rocks alternate and graduate into micaceous, chloritic, and argillaceous schists, we may reasonably inquire whether the stratified varieties of diallage and serpentine are not recomposed rocks altered, like some gneiss, by subsequent application of heat.

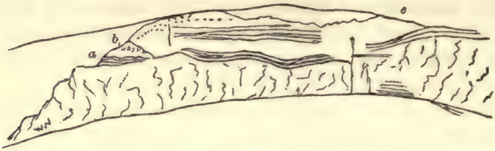
In the northern Apennines Brongniart has remarked the following general order of succession downwards:—1. Serpentine. 2. Diallage rock, in the upper part assuming the aspect of serpentine (at Rochetta, north of Borghetto, near Spezia), consisting partly of red crystallized limestone. 3. Jasper rock in thin laminæ. Below these are limestones and marly schists, common in the Apennines. In Monte Ramezzo, north-west of Genoa, the serpentine is placed on limestone and talc schist, the limestone is in thin tortuous beds, and is as it were dissolved with the shining slate and steaschist. The direction of the serpentinous masses in the northern Apennines, to which the elevation of that part of the range is ascribed, is east south-east, which is the same as that of the Pyrenees, and of some serpentine rocks about Como.

Greenstone.

This rock, a mixture of felspar and hornblende, abounds in Scotland, which has been long and not unjustly considered classic ground for the pyrogenous rocks. We shall take as an example of the occurrence of greenstone the phenomena in the vicinity of Edinburgh, which have contributed so powerfully to support the philosophical fame of Dr. Hutton. The interesting eminences of Arthur's Seat, Salisbury Crag, the Calton Hill, and Edinburgh Castle, are all composed of trap rocks associated with various sandstones and shales of the carboniferous system, and the labours of art have added to the admirable exhibitions of nature.

Salisbury Crag.—In Salisbury Crag is a very fine section of unstratified greenstone enclosed between stratified sandstone, conglomerate, shale, and ironstone nodules, and it is easily seen that both the igneous and sedimentary rocks are altered at their formation. Masses of sandstone and conglomerate, of various forms and magnitudes, are insulated in a confused manner within the greenstone, and portions of greenstone interposed among the sandstones. No dike appears; but small veins of calcareous spar, occasionally metalliferous, cross the line of junction. The accompanying drawings and references will sufficiently explain the most interesting phenomena observed, and give a general view of the face of the cliff, as it appeared to the writer in 1826. The letters of reference, *a*, *b*, *c*, mark points

of which details are given below. On a nearer examination, the point *a* shows greenstone gradually changing to a red colour and

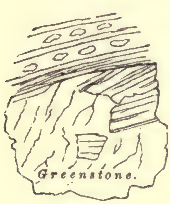


357

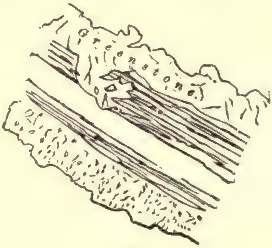
finer grain near its upper surface, on which rest beds of sandstone, ironstone, and shale, as under:—

1. The upper part of a greenstone mass, fine grained, and of reddish colour. Veins of calcareous spar, with micaceous iron ore, divide the upper part of this mass, and pass through Nos. 2 and 3 above.
2, 3. Mass of petro-siliceous sandstone, mixed with softer green portions.
4. The same sort of hardened sandstone, with less of the softer parts (here and there a purple tinge).
5. Argillaceous, compact, hard shale of a purplish or green colour, and subconchoidal fracture.
6. Red argillaceous ironstone in green shale.
7. Sandstone beds, reddish and indurated.

At the point *b* (fig. 357) a nearly similar series of alternating stone and shale rests on very similar trap. A portion of sandstone is engaged in the trap, and other signs of violent intrusion occur.



358



359

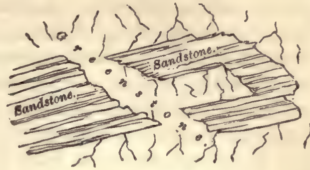
At the point *c* hard red sandstone flags, without ironstone, rest on reddened greenstone.

A large quarry at the south end of Salisbury Crag affords an excellent section of sandstone beds *below* the greenstone. Figs. 358 and 359 are taken from this quarry.

In fig. 360 the greenstone, reddening below, rests on jasperized sandstone, which is much broken and confused in places. Below

this is green shale, covering red and white sandstone with conglomerate. Fig. 361 shows portions of sandstone enclosed in the trap,

360



361

which grows redder towards the contact with the strata below. The aspect of a portion of sandstone fairly enclosed in trap is seen in fig. 361.

Some observations of Lord Greenock on the appearances presented by a section of the compact greenstone and sandstone strata in the Castle Hill, Edinburgh, show the effect of convulsions acting upon both of those rocks since the eruption of the lithoid lava. At some points of this hill the usual transformations of the sandstones, &c., happen in contact with trap; but in one place beds of sandstone and marl are seen in a state of great disturbance, thrown in angular positions upon tabular greenstone, and not in the slightest degree altered as to hardness or aggregation at the junction. Possibly the explanation which applies here, *viz.*, that the junction of the igneous and stratified rock has been occasioned by convulsive movements, which have lifted them both in a *solid* form, may be found applicable to some other cases in which trap rocks appear to exercise no transforming influence on the contiguous rocks.

Basalt.

This rock is a mixture of some kind of felspar, augite, and oxide of iron, with admixtures of olivine and other minerals.

The researches of Dr. Berger, Dr. Buckland, and Mr. Conybeare, on the north-east of Ireland, furnished a highly interesting memoir from the pen of the latter geologist.* The coast between Belfast Lough and Lough Foyle is one boundary of a large tract reaching westward to Lough Neagh, and including the river Bann, which is almost wholly occupied on the surface by basaltic rocks rising at intervals to eminences of 1,320, 1,820, and 1,864 feet above the sea. Under this immense overlying mass of basalt are found several members of the English series of strata not known else-

* Geol. Trans., vol. iii.

where in Ireland. 1. Chalk, agreeing with the lower beds of the English series. 2. Mulattoe, an Irish name for the green sand of English geologists. 3. Lias limestone (without any other rock of the oolitic system). 4. Beds of red marl, gypsum, and salt, resting on variegated sandstone. 5. At the north-eastern and south-eastern extremity, coal measures, consisting of red sandstones and shales with inferior coal, appear below all the other strata. The mulattoe and lias are often wanting in the section. The superincumbent basalt is estimated to have an average thickness of 545 feet, (in Benyavenagh it is 900 feet, in Knochlead 980 feet), and its superficial extent 800 square miles.

The phenomena presented by the basalt, exposed along so great a length of coast, are various and remarkable, and we are not only delighted with the magnificent colonnades of Fairhead, and the geometrical pavement of the Causeway, but instructed by the clear exhibition of the effects of dikes dividing both the congenerous basalt above and the calcareous strata beneath.

The immense mass of trap rocks in this district exhibits, besides basalt, which is the most abundant material, greenstone, clinkstone, porphyry, wacke, and red ochre. Near the Causeway, the cliffs, according to Dr. Richardson, consist of alternating basalt and red ochre, in the following order downwards :—

1. Basalt rudely columnar, 60 feet.
2. Red ochre or bole, 9 feet.
3. Basalt irregularly prismatic, 60 feet.
4. Columnar basalt, 7 feet.
5. Intermediate between bole and basalt, 8 feet.
6. Coarsely columnar basalt, 10 feet.
7. Columnar basalt, the upper range of pillars at Bengore Head, 54 feet.
8. Irregularly prismatic basalt. In this bed the wacke and wood coal of Port Noffer are situated, 54 feet.
9. Columnar basalt, forming the Causeway by its intersection with the plane of the sea, 44 feet.
10. Bole or red ochre, 22 feet.

11, 12, 13. Tabular basalt, divided by thin seams of bole, 80 feet.

14, 15, 16. Tabular basalt, occasionally containing zeolite, 80 feet.

The stratified rocks in contact with the trap have undergone remarkable changes in several localities.

At Portrush, the trap (a rudely prismatic greenstone) overlies and perhaps alternates with a flinty slate, which contains numerous impressions of ammonites, belonging to the lias shales. This transformation of lias shale, which reminds us of the more extensive phenomena of the same kind in Savoy, was formerly adduced as an argument for the aqueous origin of basalt! Most of the alterations of stratified rocks on this coast are effected by basaltic dikes, which divide both the overlying masses of trap and the subjacent strata.

At the foot of the hill called Lurgethan, basaltic dikes traverse the red sandstone conglomerate, which is indurated near the contact so as to resemble compact hornstone.

The coal measures, underlying the basalt of Fairhead, are crossed by dikes which have changed the ordinary shale into flinty slate, hardened and pyritized the sandstone for 15 yards, and converted the coal to a cinder. The chalk is affected by many dikes to such a degree as to be converted to a real marble, for 10 feet or more from the side of the basalt.

362 The Giant's Causeway.

The order of effects is first a yellowish tinge of colour, then a bluish-gray colour and compact texture, then a fine grained arenaceous aspect, next a saccharine granulation, and finally close to the dike the chalk is altered to a dark brown crystalline limestone, with flaky crystals as large as those in primary limestone. The flints in the altered chalk assume a gray-yellowish colour; the altered chalk is highly phosphorescent when heated. Examples occur near Belfast, at Glenarm, in Rathlin, and other places. Near the top of the stratum of chalk which crowns the cliffs of Murloch Bay, is an interposed bed of wacke 5 or 6 feet thick. For proofs of local violence accompanying the exhibition of the basalt, and many interesting details, the original Memoirs may be consulted.

The basaltic formation of Upper Teesdale in Yorkshire has been described by Professor Sedgwick, and its continuation through Northumberland by Mr. Hutton; and we can bear witness to the merit of their researches. The great mass of basalt (called whin sill) lies

in a pseudo-stratum of most irregular thickness, enclosed among the strata of the carboniferous limestone series, generally in one particular part of the series, so that in the valley of the Tyne its place in the section is constant, and we think it occupies generally the same situation in Teesdale, though in Weardale another layer of basalt occurs. We cannot doubt that it was erupted from several local centres or lines, and that its thickness at different places was effected by their proximity to the eruptive channel. In the short space of six miles, from Caldron Snout to Hilton Beck, its thickness is diminished from 200 or 300 feet to 24 feet, and farther south it disappears totally. But to the northward the range is (interruptedly) continued to the sea-coast of Dunstanborough.

No dikes pass from this mass (in Teesdale) into the rocks above or below; so that a first view of the case suggests the belief that it was poured out as a mass of submarine lava upon the yet incomplete deposit of the carboniferous limestone. Professor Sedgwick, however,* maintains that it was injected from below amongst these strata, and that it penetrated between the planes of the strata by violently uplifting them.

The strata in contact are affected by the basalt in several ways, which may be well seen about the High Force. The subjacent shales are prismatized, so as to be mistaken for basalt, generally much debituminized, so as to become gray or whitened, and rendered brittle by condensation, but not much hardened. The sandstones are in several places highly hardened, rendered brittle and full of fissures, and much whitened. The limestones below the shale are remarkable for having their top bed full of iron pyrites. Those above, but not in contact with the basalt, are for a large tract of country totally changed from a full blue, hard, rather crinoidal limestone in the first degree to a pale blue, crystallized, soft marble, and in the extreme to a loose, granular, saccharoid rock, in which, nevertheless, some traces of organic remains (a crinoidal column) remain. But the most remarkable effect is the generation of garnets in the contiguous shale under the basalt of Cronkley scar; a case analogous to the one described in connection with the dikes of Plas Newydd by Professor Henslow.†

The igneous rocks themselves are chiefly a fine grained dark basalt, changing to a coarse grained variety of the same ingredients. Contemporaneous veins of very beautiful hypersthenic and augitic trap pass through the basalt in several points, and it is traversed by a few productive lead veins.

The connection of several very remarkable and extensive basaltic dikes with this great "whin sill" has been rather assumed than

* Camb. Phil. Trans.

† Geol. Trans.

proved. In fact, there is no evidence of any one of these dikes being traced into the whin sill, and as some of them pass into the upper coal measures, and one divides magnesian limestone, lias, and oolites, we prefer to consider them of different ages, though certainly related to the same local centre of igneous expansion. Successive injections of similar igneous rocks, at remote geological intervals, seem to be indicated by the phenomena.

These dikes pass in directions to the east north-east, east south-east, and nearly east, and the lines which they take are so straight through all sorts of rocks, their respective breadths, and the quality of the rock in each, so nearly uniform, though in these particulars they differ from one another, that, considering their extraordinary length, we may safely rank them as among the most remarkable phenomena of English geology. The Cleveland or Cockfield dike, in particular, ranges for seventy miles through the coal series, (where it chars the coal, hardens the sandstones, and debituminizes the shales,) the magnesian limestone, the lias shales and sandstones of the oolite series, which are affected like the coal system below. Generally it is a nearly vertical dike, but at Cockfield Fell is subject to oblique expansions of a singular kind.

The dike which passes east north-east is remarkable for having a small vein of lead ore running by the south-east side of it, and for converting the shales through which it passes to the state of a soft, whitish shale, called pencil bed, like those in connection with the whin sill. It does not cut through the magnesian limestone.

The magnificent cave of Staffa is fashioned in vertical prisms of basalt, between rows of which the eye fixes on the distant vision of Iona. Over the cave the basalt is in smaller prisms, lying obliquely.

363 Fingal's Cave (Staffa).

Melaphyre, Pyroxenic Porphyry.

The history of this rock, which has a base of augite or pyroxene, holding crystals of felspar, is indissolubly associated with the name of Leopold Von Buch, who, by a series of observations, chiefly founded on a survey of the southern flank of the Alps, has been led to form the remarkable opinions—1. that the elevation of the eastern range of the Alps, since the tertiary epoch, was contemporaneous with and dependent on the eruption of melaphyre; 2. that the dolomites of the Alps were produced from ordinary limestone at the same time and with the same dependence. The line of dolomites and melaphyres extends (interruptedly) from Bleiberg to Lake Lugano; but the occurrence of so many masses of dolomitic limestone in other situations than where melaphyre shows itself, must render inconclusive the inferences drawn from their connection in the Alps. Neither is this connection always very evident. On the contrary, even at Lugano, it is rather *near* the augitic rock than in contact with it that the limestone is dolomitized. Von Buch's own map and sections* would hardly lead to the opinion that the dolomitization of the limestone was especially due to the presence of melaphyre. For between the dolomite and melaphyre of the peninsula of Lugano, mica schist and another kind of porphyry intervene; and on Monte Argentera, the limestone which lies upon the melaphyre is not dolomitized. De Beaumont admits that it is even rare to find the dolomites near Lugano in actual contact with melaphyre.

It would, however, be unjust to Von Buch to reject the hypothesis on this account. He himself says it is to gaseous eruptions accompanying the pyroxenic eruption that we must ascribe the alterations of rocks.

The influence of these exhalations might be felt far from the main fissures occupied by melaphyre, and De Beaumont generalizes the phenomena so as to refer the production of dolomite to the exterior line of fracture of the primary rocks; that is, to the line which now divides the undisturbed from the disturbed rocks.

The view is thus entirely changed, and certainly rendered more philosophical. Whatever may be its fate in this amended form, geologists will have been taught by it to investigate generally what connection there may be between certain phenomena of alteration of rocks, certain lines of disturbance, and particular erupted mineral aggregates; and thus the field of research into the conditions of the local metamorphism of stratified rocks is greatly widened, and brought into nearer relation with the speculations concerning general alterations of the primary strata around granitic nuclei and axes of elevation.

* Ann. des Sci. Nat., tom. xviii., pl. vii.

Claystone.

In the cliffs of Corygills (Arran) are several claystone dikes. One of these slopes at a considerable angle through the sandstone cliff, and, being very wide, shows a columnar structure in the middle rectangled to the plane of the dike; along the sides it is slaty. Between the columnar porphyry of Drumadoon and the Coves on the west side of Arran may be seen no less than five interpositions of claystone among the sandstone strata, mostly exhibiting a rude prismatic structure.

Near Tormore is the celebrated arched vein or dike of claystone represented by MacCulloch, and considered as composed of ellipsoidal concretionary layers by Boué. It is redder and softer in the middle than at the sides; it divides strata of red clay and white sandstone. Great variety of claystones occurs in the Pentland hills.*

Claystone Porphyry.

Trachytic porphyry, (Boué,) clay porphyry, as it is termed by Jameson, occurs on the western shore of the Island of Arran in considerable variety. It appears in the cliffs in huge overlying masses, and on the sandstone shores in dikes of great width. At Drumadoon many interesting exhibitions of it occur. We extract the following brief notices from a journal of observations in 1826 :—

A dike (*a*) of clay porphyry 20 feet wide, ranging south 40° west, includes large modified felspar crystals, which are sometimes nodular in external figure. On the south-east side is a contiguous vein of greenstone. The porphyry encloses masses of greenstone; it is not prismatic. A huge mass of clay porphyry, like a dike or rather interposed bed, dipping south, has on the south a layer of more basaltic aspect, the two being united in one specimen. In the fine range of clay porphyry columns at Drumadoon, which are 60 or 80 feet high, occurs a dike of greenstone passing in a line of double flexure obliquely through the pillars. At the base of these columns is a layer of more decidedly basaltic rock with few crystals of felspar, through which the same prismatic structure passes. Towards this great mass the dike (*a*) tends, and is said to join it. A very wide dike of clay porphyry, ranging north 60° east, (beyond the Coves,) has greenstone on each side, and also encloses greenstone.

Amygdaloidal Trap.

The Hill of Kinnoul, one of the most remarkable masses of trap rock in Scotland, rises near Perth, from out of the great area of red

* Professor Jameson, Wern. Trans., vol. ii.

sandstones which lie against the primary strata of the Highlands. Its height above the plain of the Tay is stated by MacCulloch* to be 600 feet, and it shows precipitous faces to several quarters. The greater part of the hill consists of an amygdaloidal rock, whose basis varies from well-characterized basalt to wacke. The substances which impart to the rock its amygdaloidal character are, green earth, calcareous spar, quartz, and calcedony. Green earth, or chlorite, occurs in nodules generally small and round; it also invests the roundish nodules of calcareous spar, which are crystallized within but externally accommodated to the shape of the cavity in the rock, or to the crystals of quartz which sometimes line the cavity. The spar is sometimes crystallized at liberty in a cavity of quartz or agate.

The quartz is found to vary by several shades into agate and calcedony, which latter sometimes appears in a stalactitical form hanging downwards in the cavities of the amygdaloid. Alternating zones of quartz and calcedony sometimes appear in the same nodule; amethystine quartz also occurs, and we have in Kinnoul almost every variety of angularly zoned agates. Veins as well as nodules of calcareous spar and quartz divide the rock, and more rarely sulphate of barytes, chert, and agate. Veins of heliotrope have also been found, but without the red spots. MacCulloch thinks there is not the least reason to doubt that the substances now filling the cavities of the amygdaloid have been introduced at some period since the cavernous aggregation of that rock from a state of lava.

Shales and sandstones are hardened and altered, and much confused at their junction with the trap. A remarkable case of seeming prolongation of thin masses of the shale into the substance of the trap, so as to resemble veins, is described and represented by MacCulloch.† In these seeming veins the laminated texture of the schist disappears.

Alternations of amygdaloid and sandstone are frequent about Oban.

Wacke.

Respecting this softest of the trap rocks, we shall only observe, that in the Calton Hill, Edinburgh, it forms part of those variable masses which sometimes may be called amygdaloid, sometimes porphyry, and not unfrequently assume the aspect of breccia; being likewise traversed by numerous small veins or strings of calcareous spar. In the superior and eastern parts of this hill wacke alternates with bituminous shale and nodules of argillaceous ironstone, in many repeated strata dipping to the east. At the surfaces of junc-

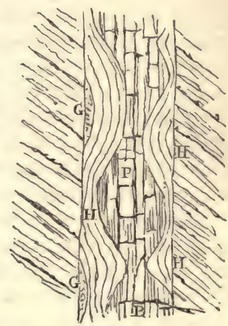
* Geol. Trans., vol. iv.

† Geol. Trans., vol. iv., pl. xi.

tion there sometimes appears a gradation from one rock to the other; and it does not appear that any decided marks here occur of the action of heat upon the shales.

Pitchstone.

As before observed, pitchstone occurs in the Isle of Arran both in dikes and interposed beds among the sandstone strata. The western coast is particularly interesting in this respect. The same cliffs which exhibit so many claystone masses alternating with sandstone, contain also parallel short bands of pitchstone probably connected with the neighbouring dikes. One of these dikes, about 30 feet wide, is curiously mixed with hornstone, and for the most part bordered along the sides by greenstone. The disposition of these substances in the fissure will be understood by reference to the horizontal plan, fig. 364, where the letters H, P, and G, are placed against the hornstone, pitchstone, and greenstone, respectively. The pitchstone is generally of a dark green colour, fissured longitudinally into rude prisms, which are joined transversely at about two feet distance, or concreted into smooth conical masses. It seems to pass gradually into the hornstone, which is laminated parallel to its bounding surfaces. The dike appears in one place to deviate from its vertical course and to go under a portion of the sandstone. A greenstone dike, which is nearly right angled to the course of the pitchstone, is shifted by it.



364

In another dike, one side is yellow pitchstone closely approximating to claystone, within this light green and red stripy pitchstone, then siliceous splintery stone in irregular masses (hornstone), and the opposite side is greenstone. Another of these curious dikes is green pitchstone on each side, then red pitchstone, and in the middle dark gray hornstone.

The pitchstone bed at Corygills is 15 feet thick; a dark green or black rock, enclosed between strata of sandstone, which are hardened towards the junction. The pitchstone is marked by lines parallel to its nearly level surfaces, and these are crossed by the smooth distant vertical faces of prisms. The lower part is porous; between it and the sandstone beneath is a white crumbly or fragmentary mass soft as steatite, which it much resembles.

Trap Tuff. Porphyritic Breccia. Volcanic Sandstone.

Re-aggregations of the disintegrated or fragmented materials of trap rocks are generally known under the vague name of trap tuff, and compared with volcanic tuff, sometimes without much reason. Amongst the slaty rocks of Cumbria, in Glen Coe and Ben Nevis, fragments of felspathic and porphyritic rocks are frequently found united into a solid breccia; under Arthur's Seat and in the Calton Hill recomposed irregular strata, chiefly derived from fragmented rocks of igneous origin, appear associated with ordinary greenstones, porphyries, and basalts. In many instances these have no just claim to be ranked with the pyrogenous rocks, but should be transferred to the class of tumultuary and local aqueous deposits: the circumstance that the principal portion of the ingredients is of *igneous origin*, is not probably confined to these rocks, but is often, perhaps with as much truth, ascribed to the whole mass of sedimentary deposits from water.

In the vicinity of Oban, in juxtaposition with some interesting amygdaloids and altered shales, sandstone beds, composed of the grains of disintegrated trap rocks, are found resting on conglomerate, amongst whose pebbles are granite, porphyry, quartz, red and white amygdaloid, fine grained basaltic trap, sandstone, jasper, &c.

Murchison found, along the South Wales border, many examples of the occurrence of sandstone composed of the ingredients of trap rocks. A little removed from the steep slopes of the Wrekin and Caer Caradoc, rocks of this kind occur in beds, and contain organic remains, but in all respects of composition strongly resemble greenstone. This was noticed by Aikin. At the southern extremity of the Wrekin, the stone is of a dark green colour, and is evidently composed of the ingredients of greenstone and syenite with a few scales of mica. Near the Caradoc these beds contain much decomposed felspar. They have been attributed to submarine eruptions of volcanic substances in such a state of disintegration as to mix with the sea water, and be diffused over considerable breadths of the bed of the sea.

CHAPTER XVII.

MINERAL VEINS.

The circumstances attending the occurrence of mineral veins in the rocks, their intersections with each other, and the arrangement of their mingled metallic and sparry contents, have been sufficiently studied to ascertain that these valuable elements in the adaptation of our planet to the wants of its inhabitants have been subjected to a great variety of processes depending possibly on one general law, but greatly modified both in combination and energy by local and periodical conditions. In the vague language of imperfect science, we say, many *causes*, separate or variously combined, have been concerned in the production of mineral veins; and it is probable that the most advantageous mode of investigating their origin, consists in the attempt to infer from the mass of facts already brought together, what are, respectively, the spheres of action and limits of intensity belonging to the several processes concerned; and afterwards, from a more general contemplation of these processes in their various degrees of combination, to rise to a comprehensive notion of their connecting laws and general cause.

This is not the mode usually followed by writers on mineral veins. Neglecting the general fact of the complication of the phenomena, they have been mostly anxious to try their bearing individually, or in mass, upon the perfectly general question of igneous or aqueous agency, and thus nothing was explained. A vast abundance of minute information on veins has been irrecoverably wasted; and the experienced miner laughs at the reasoning of the half-informed mineralogist, contemptuously rejects his theory of veins, and contents himself with believing that the facts are inexplicable. This dissociation of observers and reasoners is the true cause of the comparatively small advantage which has been derived to geology from the immense and various mines of the British Isles; on the one hand we have the greatest possible variety of phenomena, on the other the full extent of the resources of chemical and mechanical philosophy, but these have not been combined. If the zoological principles of geology are better established and more fertile in deductions than the mineral principles, it is not because our knowledge of organic nature is more advanced than the science which treats of the constitution and agencies of inorganic matter, for the contrary, perhaps, is true, but because in the one case the ancient effects and the modern laws of action have been brought into mutual illustration, in the other deprived of all connection.

In order to prosecute the investigation according to the principles which we have stated to be the best, we must limit our inquiry to those subjects most distinctly connected with metallic accumulations in the rocks. To support inferences concerning the general laws of processes which have produced mineral veins, we may with great advantage include the history of basaltic and granitic, and porphyritic dikes; but for the discovery and estimating of the processes themselves only those effects must be examined in which they are especially concerned.

Though in some instances the distinction between rock dikes and mineral veins be imaginary, they are in general clearly contrasted by the nature of the substances which they contain. In the former case, crystallized minerals of the same kind as those great interior masses of consolidated rock from which they often are evidently ramifications; in the latter metallic substances which are mostly not known to exist in nature except in these situations and in other very similar or distinctly related to them by position, and crystallized or earthy minerals, seldom of the same kind as those which occur in any of the rock dikes. To this general rule quartz is one of the most striking exceptions; yet even in this instance it is remarkable that the quartz of veins is of a different aspect from that mingled with the ingredients of granitic and trap rocks. We must therefore take the presence of metallic matter and certain nonmetallic substances usually connected therewith, and commonly called vein-stuff, as the leading characteristic of the mineral veins whose history we are now to examine, and connect with these all other cases of metallic aggregations or occurrences of the vein-stuff which seem referable to the same or analogous processes.

This view embraces the following points of research:—1. What substances are found in mineral veins and repositories. 2. The manner of their aggregation or mixture. 3. The situations of their occurrence. 4. The relations between frequency, arrangement, and contents of the veins, nature, age, and position of the rocks in which they occur.

Substances in the Veins.

What Substances, &c.—The simple minerals which occur in veins and analogous situations are far more numerous than those which are found as component parts of the rocks. Igneous rocks, and especially those of modern volcanic origin, hold a very great variety of nonmetallic substances, some of which also occur in veins; but it is almost exclusively in this latter that we are to seek the metals in their pure state, or alloyed with one another, or mineralized by combination with sulphur and other combustibles, with oxygen, chlorine, and other gases, or converted into salts by union with various acids.

Every elementary substance yet discovered by chemists exists in the earth; and it is probable that none of these are entirely absent from the solid contents of mineral veins, though this has not yet been shown to be the case for iodine and bromine, which seem universally present in the modern ocean, and azote, which appears in an especial manner devoted to the atmosphere and to the organic portion of nature.

Alloys.—The metallic substances seldom occur pure, sometimes in alloys, similar for the most part to those now producible by the chemist, as silver, antimony, cobalt, nickel, iron, with arsenic; silver and nickel with antimony; lead, gold, silver, and bismuth with tellurium; silver with mercury; platinum with gold, &c. The only known circumstance which stands as antecedent to the production of such alloys is heat, produced by either chemical or electrical action; and perhaps there is no *single fact* connected with the theory of veins on which the conclusion of the influence of heat in their production might be more securely based. The rarer occurrence of *pure* metals affords an argument perhaps of less force, but perhaps we may draw the same inference from the very numerous class of metals mineralized by union with combustibles, as sulphur, phosphorus, carbon, selenium, &c., the formation of which, according to the state of our knowledge of chemical forces, is in many instances a direct compound of heat, as the solidification of them is, in other instances, the result of cooling.

Oxides and Salts.—We cannot apply this general argument to the case of the metallic oxides which are very prevalent in veins; because, in the first place, these are produced under various relations to heat, moisture, and contact with gaseous substances; and, secondly, have various degrees of permanence when exposed to high temperatures, either separately or combined. Neither have we any general conclusion to present concerning metallic salts, which likewise are not rare in veins, since these are also in the same way various in their origin and degree of permanence. There is besides a difficulty attaching to this branch of the subject arising from the interesting fact that, in very many instances, metallic oxides and salts are derivative compounds from sulphurets and other primary combinations; and when this is very evidently the case, they are called epigene. This may be said to be even frequently the case with oxide of iron, carbonate of copper, and probably carbonate, phosphate, and other salts of lead.

Nonmetallic Minerals.—Besides the metallic ores which impart to many veins their most striking, if not most constant characters, various earthy minerals lie in these repositories, and, as will afterwards appear, under certain definite relations to the enclosing rocks as well as to the included metals, and with a less distinct dependence on the local situation *or mining district.* These earthy substances are

usually called the gangue, vein-stuff, or matrix of the ore. Generally they are crystallized, as quartz, fluor spar, calcareous spar, phosphate of lime, the sulphate and carbonate of barytes, strontites, &c.; sometimes appear massive, as quartz and several other minerals when the vein has no cavities in it; and sometimes the vein-stuff is entirely soft argillaceous matter, of different aspect in different mining districts. We are not aware that these soft kinds of vein-stuff have ever been analyzed, though probably some curious results might reward the labour. The Cornish mines would furnish many examples.

Rider.—In some veins masses of the neighbouring rocks are enclosed and penetrated to a great extent by little *strings* of the ore and spar, so as occasionally to be worth the trouble of working. The vein is said in this case to bear a rider. It, in fact, sometimes becomes under these circumstances a double vein. More rarely pebbles and other marks of watery action are stated to occur in soft veins.

Mode of Aggregation of the Ingredients.

In this respect there is a variety of appearances which deserve especial notice as indicating some of the conditions under which the vein was filled. In some cases, for instance, the whole breadth of the vein is occupied by one kind of substance, as lead ore, or quartz, or sulphate of barytes; in other instances, the metallic matter is interspersed in small masses through a general basis, as quartz; but, generally, the different substances which fill the vein are ranged in a definite order of succession from the sides of the vein toward the middle, in which, commonly, the metallic matter occurs in an irregular vertical table called a *rib of ore*. These variations are best observed in the proper veins, but are also to be noticed in the *nests* and detached masses of ore and vein-stuff which sometimes occur in the vicinity of the veins.

General Idea of a Mineral Vein.—The *ordinary* notion of a mineral vein is well exemplified in some Derbyshire specimens, not rare in collections, which, when cut across, show in the middle masses or a continuous rib of galena, and on each side of this, to the extreme edges of the mass (or narrow vein), layers of flour spar and carbonate of barytes in frequent alternation, all the materials being crystallized together without leaving any cavities, yet preserving their own character of structure.

365

Thus, in the diagram, *a* is the middle rib of galena, *b b*, *c c*, the alternating bands of barytic spar and fluor spar; *d d*, the masses of rock which enclose the vein, are called the walls or cheeks of the vein.

Supposed Successive Deposition of the Substances.—The contemplation of these specimens seldom fails to impress upon the mind an imperfect conviction that the several bands of mineral substances were deposited on the cheeks or walls of the vein in succession, the middle being filled last of all; and this theoretical notion has been illustrated by comparing a mineral vein to a narrow gallery whose walls were covered by many successive coats of plaster of different colour and composition. Werner adopted the notion of the unequal antiquity of the vertical layers of the vein so implicitly as to speak of the middle ribs as always of less antiquity. It is difficult to resist this impression, especially when, in addition to the circumstance of the succession of the laminæ, we observe that these laminæ are so crystallized as to turn their free terminations towards the centre of the vein, and in that direction to imprint the next layer with their own forms, just as crystals forming in a vessel shoot their points toward the part still remaining liquid, and in that direction are covered by the subsequently formed crystals. Very similar inferences are suggested by certain agates, and more distinctly by geodes in basalt, and the crystallized cavities in limestones, in the interior of shells, &c.; in which cases the hollow towards which the crystals pointed still remains.

Reasons Against this Notion.—Yet this first impression loses somewhat of its force when, instead of confining ourselves to a cabinet specimen, we examine the whole extent of a mine; for here in the first place it is very often found that the regular succession of minerals from the side to the centre is a limited though repeated phenomenon; that the rib of ore is of short horizontal, and sometimes still shorter vertical extent, diminishing to nothing, or diffused in small grains through the contiguous spars; that different metals are found in the same vein at different depths and at distant points along its course; and that both the quantity of metal and the presence of spars are dependent on the hardness, and perhaps on some properties imparted by the chemical nature of the rocks which the vein divides. Instances of this will be given hereafter.

Chemical Reasons.—The phenomena of crystallization before alluded to can hardly be thought to prove the successive introduction of the mineral laminæ into the vein; though very probably they do demonstrate the order of crystallization of these substances.

In some cases we observe indications that one kind of mineral has been formed round another as a nucleus; as for example, sulphuret of copper round icosaëdral iron pyrites in a part of Caldbeck fells, Cumberland, and more frequently in many places carbonate of copper and carbonate of lead round the sulphurets of those metals. It is very often the case that the metallic matter of the vein is collected into the middle and forms there a distinct tabular mass, called a rib

of ore, more rarely it is disseminated in the gangue. Generally, only one kind of metal abounds in the same part of the vein, but the same vein may yield lead above and copper below, copper above and tin below, or lead in one place and copper in another. The observation is frequent that ore is collected into certain vertical portions of a vein which are worked above and below level, and between which little but vein-stuffs is found in the horizontal drift. There is a vague notion amongst miners, that veins are most productive in the deep, and it is at least probable that they are less rich very near the surface.

Association of Minerals.—Werner insists on the fact, that certain associations of minerals can be traced in veins. He notices the concurrence of lead glance, and blende or calamine, and copper pyrites; of cobalt, copper, nickel, and native bismuth; of tin, wolfram, tungsten, molybdena, and arsenical pyrites; of topaz, fluor spar, apatite, schorl, mica, chlorite, and lithomarge; of brown ironstone, black ironstone, manganese, and heavy spar. He says where tin occurs, ores of silver, lead, and cobalt, and vein stuffs of heavy spar, calcareous spar, and gypsum are rarely found. Cinnabar and other ores of mercury scarcely ever occur with the ores of other metals, except iron ochre and iron pyrites.

Rolled and Fragmented Masses.—That fragmented masses of the neighbouring rocks should be found in mineral veins, cannot be thought surprising. It is a common occurrence in mining districts, both of primary and secondary rocks. Thus gneiss at Joachimsthal, clay slate in Cornwall, limestone in Cumberland, are included in the veins. Werner mentions a vein in Danielstollen at Joachimsthal, fourteen inches wide, which, at one hundred and eighty fathoms depth, was almost entirely composed of rolled pieces of gneiss, some of them nearly spherical. In the Stoll Kefier, near Riegelsdorf, a vein of cobalt was cut through by another vein of sand and rolled pieces. These examples seem satisfactory, but we must always be careful to discriminate between rolled pebbles and concretionary masses.

General Forms of Veins.—Mineral veins are usually distinguished by miners into several kinds, according to their general form and direction, because these circumstances are the most influential in the arrangement of their works. *Rake veins*, the most common and characteristic, may be considered to fill long, narrow fissures, which pass in a vertical or highly inclined direction downwards from the surface through a great thickness of the subjacent rocks, whatever these may be, and preserve nearly the same angle of inclination and the same linear direction through their whole course. *Pipe veins* are also highly inclined, and pass downwards in the same manner, but they rather resemble irregular chimneys than fissures, and are subject to great

swellings and contractions of their diameter. They sometimes pass downwards along the surfaces, and in other cases penetrate through the substance of the strata. The mines in the neighbourhood of Ecton, in Staffordshire, are on pipe veins. Perhaps we may give the same name to the irregular cavity of copper ore, which forms the celebrated Parys mine in Anglesea, and to the iron mines of Dannemora, in Sweden. *Flat veins* or *streaks*, as far as we are acquainted with them, seem hardly to deserve a special name, being only portions of rake veins which have been changed in their inclination, and made to pass for limited distances parallel to the beds. In the limestone districts of the north of England, this happens principally in connection with certain limestone beds. Williams has a title of *Gash veins* to express such as range for considerable lengths, like rake veins, but are wide at top, and grow narrower downwards, till they entirely vanish. This is a rare case; though Werner's opinion seems to be that many veins grow narrower downwards.

Strings.—Perfect parallelism of the sides or walls of a rake vein, which is the most regular of all, is a rare phenomenon. Most commonly, indeed, there is a definite boundary to the mineral masses presented by the rocks on each side, but this is only on the great scale; and the operations of mining disclose to us innumerable cracks and fissures in these boundary walls, which, when filled by metallic or sparry matters, are called strings, and are frequently worth the labour of following even to great distances from the parent vein, if, indeed, we are entitled to use this hypothetical expression. The notion of miners generally appears to be, that these strings are to be viewed as *feeders* of the vein, and in proportion to their frequency in many instances, is the productiveness of the vein. In the accompanying diagram, the vein is represented as sending out small branches or strings into the neighbouring rock. A rock thus penetrated by strings is sometimes said to be *ridered*, just as the masses which are often included in the vein, and the walls which bound it, are called *rider*. In many rocks these ridered parts are very greatly altered from their original state.

366

It sometimes happens that, in passing through rocks of various hardness, as limestone, shale, &c. the veins turn flat for a short distance on the hardest and most connected beds, (as, for example, on the Tyne bottom limestone of Cumberland,) and afterwards continue their course. These flat parts usually send off strings into the limestone, which may thus be ridered to a considerable distance.

Disseminated Veins, &c.—Sometimes the mineral is disseminated through the parts of the rock adjoining a vein, or collected in small nests and other closed cavities. This happens not only in the

Cornish mines, in killas and granite, but in those in the mountain limestone tracts of the north of England, and even in magnesian limestone. Generally speaking, we may be sure that this metallic impregnation is so related to the veins, that it is an effect of the same agent. Whatever filled the veins, also transferred to small distances from them some of their constituent minerals. Certain metals and ores are more liable than others to this lateral diffusion. Native silver, silver glance, red silver ore, native copper, tin ore, iron pyrites, and red iron ochre, are specially noted by Werner as occurring in this way. He says, copper ore, pyrites, and lead glance seldom exhibit this effect. The assertion may be disputed as to galena, which is found, as well as blende, and bitumen, and calc spar, and quartz, in closed cavities of shells, in mountain limestone, and in other strata.

Tin Floors, Stockworks, &c.—The dissemination of tin ores through some of the rocks of Cornwall, is noticed by Hawkins, under the title of tin floors.* He observes, that the whole tenement of Botallack is said to be full of tin floors. At Zinnwald, mineral beds or floors have long been the object of mining adventure. There granite alternates with the tin floors, which consist of quartz and mica, with tin ore, fluor spar, and wolfram, quartz and mica with tin ore, &c. At Breitenbrünn a floor of this kind has been very extensively worked in a gneiss rock.

The stockwork of the German miners is to be considered as a mass of rock impregnated with metallic matters, in numerous small veins, which come together irregularly, so as to make particular parts extremely rich. The working of such mineral repositories is directed by quite other principles than those which serve for straight veins of definite magnitude. The stockwork is generally opened like a vast quarry, and the excavations are prosecuted irregularly in the most favourable directions. Perhaps the copper mine of Parys mountain in Anglesea, the iron mine of Dannemora in Sweden, the tin ore mine of Geyer in Saxony, are examples of immense stockworks. Werner, however, appears to have considered the stockwork as peculiar to tin ores.

Relations of Veins to each other.

The influence which veins exert on each other may be in some measure ascertained by an examination of the phenomena at the points where they come into contact or cross each other. At these points it is very often found that the quantity of ore is suddenly increased to a large amount, and for some distance, either in one or

* Geol. Soc. of Cornwall Trans., vol. ii.

both of the veins. Many veins are productive only near such points, or yield there peculiar ores and minerals. This does not depend upon the enlargement of the vein merely, but is one of many facts which appear to indicate the agency of certain electric attractions in the disposition of the materials of mineral veins. We have heard miners say, that in certain cases neighbouring veins are subject to a kind of reciprocity, so that they are not both productive in the same ground, but where one is rich the other is poor; but this cannot be established without a very large collection of instances carefully observed.

Age of Veins.—The intersections of veins likewise furnish us with another well-ascertained class of facts, which throws light on the relative epochs of their production, independent of the evidence on this subject furnished by the rocks which they divide. When two veins cross, it almost invariably happens that one of these cuts or is continued right through the other, as a wall is sometimes continuous through another wall of brick from top to bottom. Thus, a vein of copper ore may cross and cut through a vein of tin ore, a vein of lead ore may cut through a vein of copper ore, and all these be cut through by some other sparry vein or porphyry dike. It is supposed, by almost every writer on the subject, that the relative antiquity of the veins which thus intersect one another may be immediately determined; and that in every case the vein which is cut through is the oldest of the two. Werner took this as the basis of his classification of veins, and most practical as well as theoretical miners agree in his views; but they are nevertheless controverted upon various grounds, and as the question is of great interest, it will be useful to present a short connected view of the facts bearing upon it.

We cannot make a step in this argument, except upon the admission that the veins are posterior to the rock which encloses them; in other words, that the space in which the mineral masses of a vein lie, once existed as a fissure in the rocks, and was subsequently filled up by the accumulation of the sparry and metallic matters. This is generally supposed by authors to be a self-evident proposition. It is equally allowed by the Wernerian and Huttonian hypotheses; and practical miners can with difficulty be made to understand that any doubt has been entertained on what seems to them so plain a truth.

Phenomena in Cornwall considered.—But the embarrassing phenomena of the granitic and mineral veins in Cornwall have created amongst some of the geologists of that district a strong suspicion, that veins are not to be pronounced of different antiquity on account of the circumstances of their intersection, nor to be considered as filling fissures at all; but that the veins and the rocks which enclose them are of the same origin. Even the common fact of veins passing through slate into granite, does not appear to them subversive of

their views, which would reduce to one epoch and one origin the most dissimilar chemical and mechanical phenomena. This insulated opinion has been generally neglected, as opposed to the actual state of knowledge and inference on the subject, but as it undoubtedly contains at least a portion of truth, we shall trace a few of the circumstances on which it is founded. Those who favour the opinion in question, must not be surprised at our omitting altogether what may perhaps appear to them the strongest argument of the whole, *viz.* the mechanical difficulties attending the generally received view, that veins were originally fissures of the rocks, because these difficulties have been in some cases surmounted, and in the rest are certainly more than balanced by others of a different kind affecting the Cornish theory. It is, besides, no argument for one theory that another is beset by difficulties which are left unexplained in both.

In the Neighbourhood of a Vein.—It is a general fact, that the walls of a vein partake in some degree of its characters, and that effects, apparently depending on the vein, propagate themselves into the neighbouring rocks. Thus the walls become more indurated, more crystalline, and for considerable distances are filled with the matters of the vein; and even the very substance of the rocks is impregnated with mineral combinations. In a country where the veins are numerous, large masses of the rocks may in this way be *ridered*, as it is termed in the north of England; and if such a gradation of characters could be relied on as a proof of contemporaneity of origin, this may in a few cases lead to the conclusion, that the veins and rocks are coeval.

But what is the true conclusion on this point? Is it not that these effects are locally related to the veins, because they are a consequence of their influence, or rather of the agency which occasioned them? That the ridering of the neighbouring rocks is coeval with the production of the vein may be allowed; but because these rocks are clearly defined from the veins, and fragments of them are enclosed in the veins, and the mineralizing influence which they have suffered obviously depends on the influence of the veins, we cannot hesitate to admit that these latter are of separate and subsequent origin. These facts are similar to what occur in other mining districts, where the stratification and consecutive depositions of the rocks divided by veins is perfectly evident, and where, therefore, contemporaneity of the veins is impossible.

In Different Rocks.—It is found, that when veins divide different sorts of killas or other rocks, their contents vary in some inconstant manner, according to the nature of the rocks; and, therefore, it has been sometimes argued, that the production of the one is dependent on the other. The most usual notion on this subject is, that the veins may be viewed as secretions from the rocks; and by

some this is supposed to have happened after the production of fissures; by others, by a mere internal separation of the parts of the mingled metallic and earthy mass.

This notion of the slow separation of the ingredients of rocks is in accordance with the principles and facts of chemistry, and must be often appealed to, if we would explain by *true causes* the phenomena of mineral veins; but with respect to the question before us it is indecisive, and may with equal propriety be applied to veins of fissures and veins of segregation. The same electric attractions between certain minerals in veins, and certain rocks about them, obtain in the secondary strata, as in the slates and granites of Cornwall; but if the pre-existence of fissures in the former is certain, why shall we deny it in the latter?

Contemporaneous Veins.—There are combinations of minerals in masses of various figure, which, upon very good grounds, are admitted to be contemporaneous with the rocks in which they lie; and if we choose to call by the name of veins all such distinct combinations of minerals, these certainly are contemporaneous veins. When in granite, greenstone, &c., we find particular portions either linear, tabular, globular, or in any other figure, which have a different proportion of ingredients from the other parts, and in consequence become conspicuous and distinct, except at the edges, which graduate without any sign of fissure into the ordinary mass of the rock; these may certainly be pronounced contemporaneous veins, and they have been produced by a process of secretion or segregation during the crystallization of the rock. These cases are perfectly distinct, and by contrast place in still more striking light the true relative age of veins of fissures.

In some instances veins of calcareous spar or other minerals lie *wholly included* in limestone masses, and these are properly called veins of segregation; but they are *not contemporaneous veins*, for they have clearly been fissures filled at some period since the consolidation of the rock; and the proof is, that shells, corals, &c., are split and sometimes displaced by these sparry veins, which undoubtedly occupy cracks left by the shrinking of the rock in the process of consolidation.

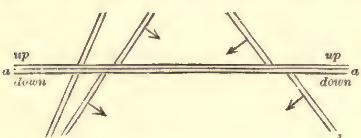
Upon the whole, then, allowing every just latitude to the doctrine of contemporaneous veins, we must admit that the greater number of veins are posterior to the rocks which enclose them.

Intersection of Veins.—This granted, we may return to the intersections of veins. The most simple case is when two straight veins cross without any change of direction, or any lateral displacement; and the order of effects appears to be the production of a fissure, and the filling of this by a vein which was afterwards broken through by another fissure, and this, in its turn, received another mineral

vein. It seems difficult to doubt the truth of this explanation; for if the vein which cuts through the other be subsequent to the fissure in which itself lies, it must also be subsequent to the vein which that fissure divides. The occasional complication of the problem by the number of intersections does not at all change its nature.

Appearances at the Crossing.—There are, however, two things to be attended to, which require further consideration. It is sometimes observed, that the vein which upon this theory is the oldest suffers a particular kind of accident at its junction with the other. It is divided into several branches on one or both sides of the cross veins, and these branches enclose portions of the neighbouring rocks. There is some difficulty in this case, however it be considered, and we must demand more exact accounts than are usually met with of these facts before attempting to reason upon them. The coincidence of this splitting of a vein with the crossing of another vein may often be only accidental; for such splitting frequently occurs in a wide vein, far from any cross course.

The fissures which have received the mineral veins are in most cases accompanied by slips or dislocations of the strata in a vertical direction, and the veins are of course subject to the same accidents of displacement. When two veins cross, and both are vertical, the lines of bearing of the two portions of the displaced vein must remain coincident after the fracture. If the divided vein be not vertical, its separated portions will have their lines of direction parallel, but not coincident; and in any horizontal plane they will *appear* to have sustained a lateral movement. Thus in the diagram, fig. 367, the cross vein *a* and the divided vein *b* are both vertical; but the divided vein *c* is inclined in the direction of the arrows, and its *apparent* lateral displacement is really due to a vertical movement. If two divided veins are inclined in opposite directions, and be dislocated by the same cross vein, they will appear to have moved laterally in opposite directions, as *c* and *d*.



367

Were we to include the cases of the inclined cross veins, and also those where the inclination of these veins varies both in amount and direction, the results would become too complicated for explanation without mathematical symbols; and we must, besides, remember that the displacement of the strata is really very seldom in a vertical direction, but generally accomplished by an angular movement from some fixed point, or round a virtual centre. We must, therefore, be very slow to admit the difficulty of the problem of the displacement of the solid masses of the earth as an argument against the received

opinions concerning mineral veins, for this principally depends on the want of precise and sufficient data.

Several remarkable cases which occur in the mines of Cornwall have been simply explained by Mr. Lonsdale, and there can be no doubt that the application of the principles of solid geometry to other complicated phenomena of that interesting region will gradually remove much of the mystery which has been supposed to hang over them.

Geographical relation of Veins.

Though, properly speaking, there is no real connection between mineral veins and the external physical configuration of the earth, yet, as this configuration is connected with peculiarities of internal structure, it is generally found, as Werner long ago indicated, that mining districts are almost entirely confined to the vicinity of mountains or elevated land, because in these situations the rocks were most dislocated by slips, and divided by fissures at the period of their elevation. It is not the absolute height of the ground, but the circumstance of its having been much exposed to subterranean convulsion that determines the prevalence of mineral veins. The rich mines of Cornwall are in comparatively low situations, but they are all in the vicinity of erupted and elevated rocks.

There appears to be no limit either of height above or depth below the sea, which defines the productiveness of veins, though in some countries the higher and in others the lower situations are most favourable.

It is sometimes found that the contents of a vein vary with the depth, without any particular geological conditions; as, for instance, in Cornwall copper is prevalent in the mines at greater depths than tin, and in the slate tract of Cumberland veins which bear lead near the surface yield copper in the deep. In other cases there appears a peculiar determination of the metallic ingredients to particular situations. The mines about Ecton yield copper; those of Derbyshire generally lead; in the Pennine chain the veins generally yield lead, but toward the eastern and western limits of the district copper becomes less uncommon.

The length of a vein of fissure is perhaps hardly in any case certainly known; because, when it ceases to be worth working, it is for all the ordinary purposes of mining said to be dying out, or cut out, or ended. The richest veins are productive for limited lengths, but the fissures which they fill may be, and often are, extended far beyond the spaces occupied by metallic impregnations. Some of them are known to extend, and to be productive for many miles in the Harz, in Cornwall, and in the north of England. The width

is various in different veins, but generally nearly constant in the same vein. A width of twenty feet is very unusual. Most veins are less than six feet wide.

Directions of Mineral Veins.—There is a peculiar geographical relation of veins which is very difficult to understand, but which is so general that it may eventually be of the greatest value in correcting and perfecting our theories concerning them. This is the general *direction* of the veins. The most general direction of the great dikes and faults in the north of England may perhaps be defined to be nearly east and west. But this is much more certainly true with respect to the mineral veins of the limestone districts of Weardale, Allendale, Alston Moor, and all the mining districts of Yorkshire; and it is equally recognized in the primary tracts of Cumberland, Westmoreland, and Lancashire. This is so general a fact, that the east and west veins are called right running veins, while the few which range more nearly north and south are called cross courses. These latter are seldom rich in metal. They often cut through and shift the right running veins laterally, as both of them shift the strata vertically. There is often to be observed a sort of compensation in the dislocating effects of veins. In Weardale most of the veins throw up to the north, while the parallel courses in Allendale and Alston Moor throw up to the south. The lead veins of Flintshire and Cardiganshire have the same east and west direction, and so have those of Mexico.

The lodes and veins of Cornwall are most generally east and west veins, or nearly so; and these, according to Mr. Carne's* excellent Memoir, are the *oldest veins* in that district, being traversed by the oblique veins and by the cross courses elvans and flukans. But not all the east and west lodes are of the same age, the tin being older than the copper; neither are all the east and west tin veins of one age, for those that underlie to the north are generally traversed by those that underlie southwards. These curious generalizations are not to be overthrown by particular discordances. Their value may one day more fully appear, and they are certainly supported by analogous though less varied occurrences in other countries.

Directions of Veins of different Antiquity.—The general order of their dates may be thus expressed:—

1. Oldest, east and west, tin veins underlying to the north.
2. East and west, tin veins underlying to the south.
3. East and west, copper veins generally east to south.
4. Oblique or *contra* copper veins, generally east 30° to 45° south.
5. Cross courses not metalliferous, north and south.
6. Copper lodes of more recent date and lead veins.
7. Cross flukans or clay dikes nearly north and south.
8. Slides in all directions, but generally east and west.

* Trans. of Geol. Society of Cornwall.

The porphyritic and other dikes called elvan courses are very generally divided by the veins, and seem to be of greater antiquity. Werner has observed this geographical relation of mineral veins, and states the two following cases. In the mining district of Freyberg are two classes of veins very different from one another. One of these classes consists of veins which run from north to south. The veins of this contain lead glance, black blende, iron, copper, and arsenical pyrites, quartz, and brown spar. This is the oldest vein formation. The second class of veins, which always traverse the former, and are never crossed by them, contains lead glance, radiated pyrites, heavy spar, fluor spar, and quartz. They strike between the sixth and ninth hours of the mining compass (east to south-east).

The mining district of Ehrenfriedesdorf contains veins of tin and silver glance. The tin veins are always traversed by the silver. The direction of the first is between the sixth and ninth hour (east and south-east), that of the last from the ninth to the third hour (south-east, south, south-west).

Another Geographical Relation.—There is observed in some mining districts another remarkable relation of metalliferous veins to geographical lines. Though in the north of England the most frequent direction of the *veins* be east and west, the *mining districts* seem rather to be ranged in lines from north to south. The nature of this relation will be more easily understood, if we add that both in Cornwall and in Cardiganshire, where the veins are also most frequently east and west, Mr. J. Taylor has observed lines of greater productiveness ranging nearly north and south across the bearing of the veins. These curious notices suggest the inquiry whether the lines of productiveness are dependent on any principal axis of dislocation or on the occurrence of cross courses. The former case seems to be vaguely indicated by the phenomena in the north of England. Perhaps the latter may be more applicable to Cornwall.

Connection of Fissures and Main Joints.

The remarks on the joints of rocks in pp. 40-43 may be referred to as sufficient to show the importance of studying their direction in connection with that of the fissures of mineral veins. It is certain that in the limestone dales of the north of England mineral veins are sometimes directed along the master joints of the rocks, also that in the slate tracts veins and dislocations range along the cleavage planes of the slates. (Craven.) Dr. Boase has noticed the same thing in the slate tract in Cornwall, and such observations will doubtless be multiplied. Mechanical considerations might have led us to anticipate this result; for the main joints and cleavage planes would often be the lines of least resistance, and yield more easily

than other parts to any eruptive or depressing force applied to the planes of stratification. The direction of the master joints is certainly definite over large tracts of country; and if we should find eventually that mineral veins have commonly taken the same course, their regularity will no longer be an argument against, but an additional evidence for the vertical movement of the masses.

Relation of Mineral Veins to the Rocks which enclose them.

The relation of mineral veins to the rocks which enclose them offers a wide field of inquiry, which has been much studied, and yet is very little understood. It is difficult to distinguish clearly between the *accidental* and the *necessary* association of the phenomena of veins and rock masses. It is perhaps hardly possible at present to form a satisfactory opinion as to the amount of effects produced by causes acting from distant centres of force. We are in ignorance as to the subterranean operations of electrical and calorific agents still constantly going on; and to these theoretical difficulties must be added the unconquerable impediments to accurate and varied observation of the facts on which inferences are to be founded. Minute analogies of the relation of veins to the adjacent rocks would therefore at present be very unsatisfactory and hypothetical, and we must be content with the results which may be gathered from wide and general comparisons of phenomena on the grand scale. We shall confine the inquiry to metalliferous veins.

Relation to the different kinds of Rocks.

Considered as to their chemical nature, rocks may be classed as calcareous, argillaceous, siliceous, and mixed; as to their mineralogical characters, as uniform, or varied, granular, compact, or crystallized; as to their origin, aqueous, igneous, or metamorphic. Metalliferous veins occur more or less frequently in every one of these classes of rocks. In limestone, in argillaceous slate and shale, in quartz and sandstone rocks, and in rocks of mingled ingredients; in uniform slates, and fragmentary millstone grit, in granular sandstone, compact limestone, and crystallized limestone and granite; in sedimentary grits and shales, in pyrogenous porphyries, basalts, and metamorphic conglomerates. The existence of mineral veins in a rock is therefore wholly independent of the particular chemical and mineralogical nature and proximate origin of that rock; nor, when due allowance is made for the relative prevalence of the different kinds of rocks, does there appear any reason to admit that any preference or more frequent occurrence of metalliferous veins in rocks of particular kinds can be traced, *except in particular districts.*

Veins of Certain Metals.—There yet remains the inquiry whether certain metals are specially associated with or related to particular sorts of rocks. In order to answer this question satisfactorily, we must not content ourselves with instances such as tin veins and mercury veins, which occur in so few localities as to be rather dependent on their geographical position than on their geological repositories, but must cite veins of lead and copper, and disseminated ores of iron and manganese. Hardly any substance is more abundant in the mineral kingdom than iron pyrites; it occurs both in veins and disseminated crystals or concretions; and, in one or other of these states, it is associated with almost every known rock. It occurs disseminated in limestone of various kinds, as primary limestone, carboniferous limestone, and chalk; in clay slates, shales, and clays; in greenstone, amygdaloid, and basalt. Veins containing iron pyrites traverse rocks of as great diversity. Copper pyrites is not disseminated through so many rocks as iron pyrites, but it occurs in veins which traverse limestone, sandstone, and shale, clay slate, mica schist, granite, &c. Ores of manganese are also very generally diffused through rocks of very different kinds. The converse is true. In one and the same kind of rock occur veins of copper, lead, silver, and tin.

Affinities of Metals to Certain Rocks.—There are some metalliferous veins which traverse different sorts of rocks, and give us an opportunity of ascertaining whether any differences in the contents of the veins correspond with the variations of the rocks. The tin veins of Cornwall sometimes pass through clay slate and granite; they produce ores in both. "A vein that has been productive of copper ore in the clay slate, passing into the granite, becomes richer, or, what is more remarkable, furnishes ores of the same metal differently mineralized. If we pursue it farther into the granite, the produce of metal is frequently found to diminish. A change of ground is looked upon by miners as affording reason to expect an alteration for better or worse."*

In Silesia.—Remarkable instances of this relation are given by Von Dechen.† The numerous veins which cross the steeply inclined strata of greywacke in the Liegen district, are metalliferous in narrow bands *parallel* to the inclined beds of greywacke. The veins of the Kupferberg, in Silesia, bear ore only in the hornblende schist, and are impoverished in mica schist. At Joachimsthal the mica schist is traversed by quartzose porphyry in veins, which, as well as the contiguous rock, hold pyrites in mica slate. The rothegang of Elias consists of loam, and holds only uranite; where it runs between mica schist, and a porphyry vein, and where it traverses the latter,

* Taylor, Report on Veins.

† De la Beche's Manual, German Trans., 594.

its substance is a red hornstone, and it bears vitreous silver, native silver, arsenical cobalt, bismuth glance, kupfernickel, arsenic, and bismuth; but red silver, elsewhere abundant, is entirely wanting.

In North of England.—In the lead veins of the north of England, which are situated in the carboniferous limestone tract, a singular dependence is observed between the contents of the vein and the nature of the adjacent rock. The vein divides limestones, sandstones, and shales, and these are brought variously into opposition by the dislocations which accompany almost all the veins. The vein is sometimes productive of lead ore under every case of opposition in rocks. Where limestone, or schist, or solid sandstone forms the walls, its productiveness is at the maximum, but generally it is contracted in breadth and impoverished in its metallic contents, wherever it is included between walls of shale, and even where only one side is occupied by shale, the same effect is frequently observed. It would appear that the impoverishing influence of the shale is referable to mechanical causes. In the same way as the shales in a coal-pit swell out from the undisturbed parts to fill the artificial vacuities, so we may conceive them to have done into the natural fissure; this will account for the contraction of the vein. In the process of crystallization, to which all the contents of a vein are subject, it seems conformable to analogy to suppose, that the permanent walls of limestone and gritstone would permit a more early growth of sparry and metallic crystals, than the crumbling edges of shale; a supposition, perhaps, confirmed by the occasional mixture of shale in the sparry mass of a vein, where it is "nipped," as the miner says, in beds of shale. There may be something in this due to electrical affinities, and we may perhaps apply the same supposition to the cases in Cornwall and Germany, quoted above, where the deposition of the ores is influenced by change of ground.

Quantity of Lead Ore from Different Beds of Limestone.—From some or all of these causes it happens in the north of England that *certain* limestones are very much more productive than the others; in different mining districts, *different* limestones are thus favourably distinguished, but in the country of Aldston Moor, Teesdale, and Swaledale, the uppermost thick limestone is by far the most rich in lead. To prove this, and at the same time to record a valuable fact, we may copy from Mr. J. Taylor's report on mineral veins* the following statement of the quantities of lead ore actually extracted from the several sites of bearing beds in Aldston Moor in the year 1822; according to the account of Dickenson, we have added the thickness of the several beds.

* Reports of the British Association, vol. ii.

	Thickness in Yards.		
Limestone beds:—			
Great limestone,	21	20·827	Bings of 8 cwt. each.
Little limestone,	2	287	
Four fathom limestone,	8	91	
Scar limestone,	10	90	
Fine bottom limestone,	8	393	
			21·688
Gritstone beds:—			
High slate sill,	8	107	
Low slate sill,	7	289	
Firestone,	11	262	
Pattinson's sill,	4	259	
High coal sill,	4	327	
Low coal sill,	3	154	
Tuft,	3	306	
Quarry hazel,	10	44	
Nattrass gill hazel,	6	21	
Six fathom hazel,	12	576	
Slaty hazel,	4	18	
Hazel under scar limestone,	4	2	
			2·365
Whole produce of the mines of the manor, 1822,			24·053 bings.

Upon the whole there is no sufficient evidence to show that the local *production* of metallic substances is in any special manner dependent upon the chemical or mineralogical composition, or the circumstances of the formation of the adjacent rocks, though in some particular, and, indeed, many instances, we observe the *aggregation* of the substances in the vein to have been decidedly influenced by some peculiar conditions of the including rocks.

Walls of a Vein.

Alteration of Substance.—The walls or cheeks which form the more or less definite boundaries of the vein present several facts worthy of notice. In some instances they are highly indurated, as if in contact with trap rocks (north of England), very often fissured, so as to break parallel to the vein; in others it seems as if certain sorts of rock (as clay slate, both in Cornwall and Germany) were greatly softened, and even converted to clay, along one or both sides of a vein. Werner mentions the decomposition of felspathic and hornblendic rocks for a fathom from the vein. We have also witnessed the fact of limestone, usually a blue or gray crinoidal rock, burnt, as the miners term it, that is, converted to a brown granular crystalline rock. (Teesdale.) Another remarkable effect in the walls is the production of slickenside, so long known in the mines of Derbyshire, which are situated in limestone, and filled with fluoric and barytic spars, and yield lead; in those of Cornwall, which are in

killas, and with a matrix of quartz, and yield copper; in the magnesian limestone of Yorkshire, where copper or lead lines the limestone cheeks; and in the faults of the coal system of Yorkshire, where neither spar nor metallic matters are common. These and many other occurrences of rubbed surfaces along planes of fissures speak a clear language, and prove to the fullest conviction the mechanical movement of the sides of the fissure upon one another or upon the contained substances. The groovings of the surfaces, thus produced by rubbing, indicate, of course, the line of the movement; the circumstance that the polished faces are partially covered by lead ore, copper ore, &c., as the nature of the vein is, proves, moreover, that the movement was, in such cases, posterior to the introduction of the whole or a part of the mineral impregnation, so that the same fissure has been, in such cases, the plane of more than one convulsive movement. We may, perhaps, eventually draw from examinations of this phenomenon, in connection with and apart from mineral veins, some decisive results as to the time and other circumstances connected with the movements of the masses. How can the geologists of Cornwall doubt the reality of those angular movements which have left such clear evidence as the fine slickensides of some of their veins of fissures? We think with Von Dechen* that any other than the received explanation adopted above is impossible.

Relation to the different Ages of Rocks.

This Relation evident.—There can be no doubt of the fact that the local occurrence of metallic veins is in a very great degree dependent on the relative antiquity of the rocks in the district. It is in the hypozoic and palæozoic generally, and in the igneous rocks associated with them, that all the veins in Great Britain are worked. In a few instances veins of small value, producing lead and copper, pass through the magnesian limestone; but not a single example is known of a true metallic vein in the oolitic, cretaceous, or tertiary strata. The connection of metallic veins with the older rocks is not an accidental coincidence, but a constantly recurring phenomenon; and the absence of such veins from the newer strata in England cannot be resolved into any circumstances of the geographical position of these strata; for both around the metalliferous slates of Cumberland and limestones of Derbyshire the new red sandstone formation is extensively spread in contact, and yet not one lead or copper vein occurs in it. Any one who should confine his attention to the British isles might infer that the causes of the production of mineral veins had been almost wholly inactive ever since

* German Transl. of De la Beche's Manual.

the carboniferous epoch; and as a general expression this may apply to the continent of Europe, though both in the Pyrenees, and around the central granitic tract of France, metalliferous veins, apparently originating in these rocks, traverse strata of the oolitic and cretaceous systems.

The same Relation obtains in Rock Dikes.—It must here be remarked, that both in Great Britain and throughout Europe rock veins and basaltic dikes are in the same manner abundant in the primary and rare in the secondary and tertiary strata. This is one of many general analogies tending to substantiate the opinion previously advanced upon more specific points of agreement, that rock veins and dikes, and metalliferous veins, form two parallel series of igneous products developed during the same geological periods by the same general causes, acting under different circumstances upon different materials. From all our previous investigations we have been led to the conclusion, that in the earlier geological periods the chemical effects of heat were more conspicuously exerted; and if to this we join the consideration that all the disruptions by which igneous rocks were put in contact with secondary and tertiary strata must have been experienced by the older strata, from beneath which the disturbing force originated, we shall be able to perceive why the primary are so universally and the secondary and tertiary strata so partially enriched with mineral treasures and diversified by rock dikes.

Very Modern Veins.—As an example of veins of more recent date, we may quote Von Dechen's notice of the veins of Joachimsthal. In this case the dikes of basalt and wacke which divide the mica slate are themselves cut through by the mineral veins. These dikes are variously connected with great overlying masses of basalt which break into the brown coal formation. It is therefore evident that the silver, arsenic, and cobalt ores have been thrown into the veins at a later epoch than that of the brown coal tertiary deposit at the foot of the Bohemian Erzgebirge.

Werner appears to have been strongly impressed with the belief, conformable to his general theory, that vein formations might be classed as to their ages by mere examination of their component substances. When veins, even in distant countries, contain the *same* ores and vein stones, and when these are arranged in the same determinate order, he concludes that they belong to one and the same general formation. Illogical and hazardous generalizations are frequent among practical men, and are too often introduced among the valuable facts recorded as a basis for Werner's theory of veins. A prudent reasoner would scarcely venture to trust an inference for *time* upon data which indicate only definite *chemical action*, even in a limited district; and it must be with some distrust that we can

admit Werner's eight principal vein formations in the mining field of Freyberg, because he does not state *expressly* that his inferences concerning their relative antiquity were based on observations of their intersections.

The following abstract of the account of these eight systems of veins will show the kind of description which should always be given of mineral veins.

Werner's Eight Systems.—The first and oldest produces abundance of argentiferous lead glance. It consists of coarse granular lead glance with from one and a-half to two and a-half ounces of silver per quintal, common arsenical pyrites, black blende in large grains, common iron and hepatic pyrites, sometimes a little copper pyrites, and a little sparry ironstone. The veinstones are chiefly quartz, sometimes a little brown spar, rarely calc spar. These circumstances occur most generally in veins ranging from *north to south.*

The second yields lead very rich in silver. It contains lead glance large and small granular; black blende in small grains; iron and hepatic pyrites, and a little arsenical pyrites. In addition, dark red silver ore, brittle silver ore, white silver glance, plumose antimony ore. The veinstones chiefly quartz, with much brown spar and often calc spar. The veins range *south and south-west.*

The third yields lead glance with one ounce of silver per quintal, much iron pyrites, a little black blende, and red iron ochre. Veinstones quartz, sometimes with chlorite mixed and surrounded with clay. Veins range *north and south.*

The fourth yields lead glance with one-fourth to three-fourths of an ounce of silver per quintal, radiated pyrites, and sometimes brown blende. Veinstones heavy spar, fluor spar, a little quartz, and rarely calc spar. Veins range *east and west.* (To this system Werner boldly refers the veins of Derbyshire, the Harz, and also those of Gisloff in Scania!)

The fifth consist of native silver, silver glance, and glance cobalt, sometimes with gray copper ore, lead glance rich in silver, fine grained brown blende, and sparry ironstone. Veinstones, heavy spar in a state of disintegration, and fluor spar. It always occurs in the *intersections* of the first and fourth systems. (North and south, and east and west.) It sometimes is found even in the middle of the westerly veins.

The sixth contains native arsenic and light red silver ore; with a little orpiment, copper nickel, glance cobalt, native silver, lead glance, iron pyrites, and sparry ironstone. The veinstones are heavy spar, green fluor spar, calc spar, and a little brown spar. Occurs in the intersections of the fourth and fifth systems, or in the middle of veins.

The seventh is of red ironstone, with a little iron glance, quartz, and heavy spar. Occurs in the *upper parts* of veins.

The eighth and newest is of copper pyrites, mountain green, malachite, and red and brown iron ochre, with a little quartz and fluor spar.

Relation to the Local Centres of Igneous Action.

Our investigations lead directly to the inquiry, how far the geographical occurrence of metalliferous veins is connected, as that of rock dikes is known to be, with the eruption of igneous rocks and the movements of fluid masses within the globe?

Satisfactory evidence on this subject can be obtained in two ways: first, by comparing metalliferous and non-metalliferous districts of old strata in their geographical relation to igneous rocks and convulsions. Secondly, by comparing the relation to igneous agency of the locally metalliferous newer strata.

In Older Rocks.—The older rocks are not by any means universally stored with metalliferous veins any more than with rock dikes. Very large tracts in the slate rocks of Devonshire are nearly devoid of metals, but near the granitic masses of Cornwall they are abundantly supplied with veins. In the vast districts of Wales the slate rocks yield copper and lead chiefly along the western borders of the Principality, where the local centres and axes of elevation are situated. Amid the Cumbrian lakes, lead and copper veins adjoin the granitic, hypersthenic, and syenitic axes of Carrock, Skiddaw, High Pike, &c. They occur near the porphyries and traps of Helvellyn and Old Man, but the greater portion of the slates, far removed from the foci of disturbance, are devoid of mineral treasures.

In Scotland, metallic veins adjoin the granitic nucleus of Strontian.

The mining tracts of the Harz, the Erzgebirge, Hungary, Brittany, and other localities are convulsed by disruption and diversified by the intrusion of granitic and porphyritic rocks; the Ardennes mountains, which yield few veins, develop hardly any igneous rocks.

The carboniferous limestone tracts of Mendip, Derbyshire, and Flintshire, of Wharfdale, Swaledale, and Aldstone Moor, have been shaken to pieces by many convulsions, and they are very rich in lead, zinc, and calamine; but the greater part of the Yorkshire and Northumberland limestones, affected by only one or a few general elevations, are poor in metal.

In Newer Rocks.—The newer rocks are metalliferous only in the vicinity of the foci of their disturbance, as round the central granite of France, near the igneous masses of the Pyrenees and the Alps; in all which places, the metallic ores are so related to the igneous rocks that they occur only in a narrow zone at the junction of the igneous and the altered stratified rocks.*

* Observations of Dufrenoy, Von Buch, &c.

Conclusions on this Subject.—As both these methods of comparison lead to one result, we may venture to adopt it; and the more readily because, in preceding sections, we have found the geographical situation of mines to be related to the elevation of the ground, and the metalliferous strata often identical with those in which rock veins abound. Nevertheless we must not shut our eyes to some decided differences between the situations of dikes and veins. For instance, the Island of Arran is traversed by hundreds of dikes of basalt, porphyry, and pitchstone, but metallic veins are almost unknown there; Aldstone Moor is dissected like a map by veins of lead ore, but very few whin dikes occur there; on the contrary, in Northumberland and Durham whin dikes abound in the coal tracts where lead is hardly known. It is, besides, too remarkable a thing to be overlooked, that, south of Durham, barely a solitary whin dike or porphyry dike is known through the metalliferous tracts of Yorkshire, Derbyshire, Somersetshire, and Flintshire. This contrast is the more remarkable in the country about the sources of the Tyne and Tees, because there basalt has been erupted in vast quantity, and at its eastern termination appears related to several dikes of great extent. This mass of basalt is traversed by the veins in the same manner as the limestone is, and we may, perhaps, hazard the speculation that under this tract of country lay at one time melted basalt, and at a subsequent time the metallic and mineral combinations which fill the veins. Will it be thought too great a stretch of fancy to attribute this change of the igneous materials erupted in the same tract of country to movements in the internal nucleus of the globe not isochronous with the rotatory velocity of the solid superficial crust? By such an operation melted masses of different nature might at successive times lie under the same surface area.

Electricity of Veins.

Mr. Fox's Experiments.—The direction of electrical currents at small depths below the surface of the earth is a subject on which theory is at present silent, and which has only recently been proposed for observation. The observations of Mr. Fox in the mines of Cornwall, and Devon, and North Wales are still the most important of the kind. Mr. Henwood has also been engaged in many inquiries on this subject. As far as appears at present, the interest attached to the solution of this question belongs more particularly to electrical science, and, perhaps, both chemical and thermal disturbances of equilibrium may be concerned in the effect. These currents may be due to local causes. Mr. Taylor very properly observes,* that by

* Reports of the British Association, vol. ii., p. 18.

the very act by which we gain access to a vein we lay it open to atmospheric action, and consequently to decomposition. Chemical agency commences, and with it, very naturally, galvanic influences are excited. Veins containing ores little subject to decomposition have, he apprehends, been found to give little or no indication of this nature.

Mr. Fox appears to think that the direction and intensity of the currents which pass along the veins may be so related to the position and quantity of metallic matter, as to give reason to hope for some direct useful application of the results to the art of mining. But the novelty of Mr. Fox's experiments, and the connection of the currents with mineral veins, led some geologists to adopt the very hasty conclusion, that the production of the veins was mainly owing to such currents. It is very probable that electrical currents have really been concerned in the distribution of metallic ores both in veins and rocks, for when is this agency absent from any great chemical phenomena? But to conclude, without any intermediate steps, because mineral veins are channels for electricity, that they have been produced by electricity, is an inference of the same order as that which would ascribe to electrical currents the construction of the galvanic battery.

The art of the miner, founded on long experience, is gradually acquiring the aspect of applied science. To bring it fairly within the circle of inductive philosophy—to give it more exact laws, based on a surer classification of phenomena—is an object of the highest concernment for humanity. On the command which man has acquired over the various properties of metallic matter has depended much of his civilization and a large part of his power over the forces of nature. If this command may be extended, these forces may be still more completely brought within the direction of the human mind. The way to do this is to carry science into the mines, and bring miners into the class-rooms of the professors of chemistry, geology, mineralogy, and mechanics. Practice will thus become method, and experience be exalted to theory.

It is amusing at the present day to find in California and Australia the very same modes of working superficial alluvial and deep-bed deposits for gold which were practised in Gallicia and the Cassiterides for tin in the days of Pliny, and Strabo, and Herodotus,* and perhaps in equally ancient times in those hyperborean regions, those Uralian mountains, which still furnish so much gold to Europe. Probably many great mountain chains, full of quartzose and metamorphic rocks, yielded gold in the earlier ages of the world; though none of the rivers washed it away in such abundance as the

* Hist. Nat., many notices.

streams of Lydia. Not much of the gold and silver of the ancient world was obtained by mines properly so called, at least in Europe, till the heroic spirit was replaced by great commercial activity. Then the Athenians dug silver ores from Laurion, the Carthaginians obtained it from Spain, the Romans separated it from the lead ores of Derbyshire and the north of England. The peculiar mining customs, not yet extinct in Derbyshire and Cornwall, bear testimony to the high antiquity and foreign source of the art of mining, as established in these countries; while throughout the north of England such terms as groove, and sump, and toadstone * betray the later influence of German workmen.

Those who desire the prosperity of their country can hardly be indifferent to the success of the great effort now making in London to impart a sound education suited to those who engage in mining pursuits. The College of Practical Science in Jermyn Street offers instruction in all those branches of positive knowledge which a miner should know. It is a *miner's college*. Probably to make it effective, fully effective, there should be preparatory schools—*mining schools*—in Cornwall, in Derbyshire, in Northumberland. Here, probably, in the midst of the works of nature and the works of man, the student should learn to handle the ruder implements of art, and become a skilled workman, before he proceeds to metropolitan class-rooms for the study of the more delicate instruments and processes of science. It is not so easy or so pleasant, after cultivating a taste for refined general knowledge, to learn hard and rough work, as to take the upward course of converting the practical skill of a workman into the directing power of a philosophic master of mining.

* *Groove* is scarcely altered German for *a mine; sump*, a shaft below level, is clearly from *sumpfen*, a German verb *to sink; toadstone*, in which the metallic vein is unfruitful, is *todtstein*, German for dead or *unproductive rock*.

CHAPTER XVIII.

VOLCANOES AND EARTHQUAKES.*

The phenomena associated with burning mountains contribute powerfully to the interpretation of the older classes of pyrogenous rocks. Indeed, from the lava currents and cinder hills of to-day, we pass by many easy steps to those which flowed over or were heaped up in the earliest historical times; from these to others which presented the same aspect of long extinguished fires, to Strabo and Empedocles, which now they offer to Daubeny and Lyell. If there be any general differences between modern volcanic and ancient plutonic effects, it is in part attributable to the circumstance, that the modern phenomena best known to us are such as happened on the land—*subaerial* phenomena—while the evidence of the ancient fires is chiefly gathered from subaqueous lava streams and submarine beds of ashes. Much of the modern trachyte, basalt, and other melted rock has been exposed by *eruption*, and indurated at the surface; much of the ancient granite and greenstone was solidified under the pressure of seas and mountains.

As in a former page we spoke of the successive existence, in a state of fusion, of different kinds of plutonic rock under the same region, so now, the diversity of volcanic rocks in different parts of the earth's surface, leads to the conviction that, under different geographical areas, we have separately existing different kinds of melted mineral compounds. Vesuvius pours out augitic compounds; the peak of Teneriffe delivers sheets of glassy lava; the old volcanoes of France, the Rhine, and Hungary, yielded granular trachytes; but none bring up granite to be crystallized at the surface. Dr. Daubeny, uniting in his mind the most comprehensive chemical view which the subject admits, proposes, as a rule frequently observed, that the early granitic compounds are characterized by prevalence of silica—which not only unites with alumina and other bases, in treble or double atomic proportions, (forming trisilicates and bisilicates,) but, further, often appears in excess, and remains outstanding in abundance as quartz.

On the contrary, free quartz and trisilicates are comparatively rare, not only in the products of modern volcanoes, but also in the pyrogenous rocks of mesozoic eras. Among these silicates of lime

* The article *Geology*, as formerly printed in the Encyclopædia, contained an essay, by Dr. Daubeny, on this interesting subject. The present volume being mainly devoted to British geology, it has been found impossible to give here more than the briefest sketch, with special reference to Plutonic rocks. It is satisfactory to refer the reader, for a full account of volcanoes, to Dr. Daubeny's lately republished, very complete, and valuable volume.

and magnesia are prevalent; but among the granitic rocks they are rarely found. May we suggest as deserving of attention the probability that granite appears among the oldest of the igneous family because of the gradual cooling of the internal fluid mass, which, bringing into action the unequal relation to heat of silicates and trisilicates, separated these groups in zones. The former (usually more complicated) mixtures might remain liquid, while the latter (usually less complicated) separated themselves in a solid form. On this supposition, the trisilicated zone, being of less specific gravity, would lie uppermost. It would be first consolidated, and might receive a covering of strata, while the silicated mass remained liquid below. Thus placed in contact with the oldest strata of any given place, it might, on the occurrence of subsidence there, enter again

368 Naples.

into fusion, and be pressed into the fissures of those strata. A similar case is well known in Pattison's process for refining lead—the silver alloy remains fluid, while the simple lead sinks to the bottom in crystals. And carrying out this idea, the trachytic lava of one active volcano, and the doleritic lava of another, would seem to indicate the *stage* at which, in those places respectively, the volcanic process had arrived. In this hypothesis, however, the effect of local subsidence or elevation of the volcanic region must be remembered, for thus the phenomena might be *repeated*. Perhaps this has happened in Auvergne.

It is only in a few districts that any such marked succession of different volcanic rocks produced in successive times can be recognized. Perhaps it is recognized in the Katakekaumene, a district of

Asia Minor, rendered classical by the notice taken of it by the geographer Strabo.* Besides the three truncated cones which caught the attention of Strabo, Hamilton † notices about 30 older craters, a still older basaltic plateau of tertiary date, and yet more ancient trachytes.

The temperature of the lava at its efflux from a volcano is often registered as that of a red heat, say 1000° F. If derived from the earth's interior heat, we must suppose the liquidity to have been communicated upward from a depth of 8 or 12 miles (950°×15 or 20 yards = 14,250 or 19,000 yards). The agent of uplifting being by common consent admitted to be gaseous, or the vapour of water, we find that at such a heat the steam power would be equal to balance

369 Guadaloupe.

a column of liquid lava three, four, or five miles in height. Volcanic explosions are generally admitted to be the effect of the expansion of an aëriform fluid collected irregularly below the crust of the earth. This fluid has been supposed to be *steam,* generated by contact of water, heated by the interior masses ;‡ extricated from *spheroidal* water by *cooling* of these masses ;§ or *gas* separated from the liquid subterranean ocean, during the cooling and consolidation of it, and accumulated to high pressure above it. In regard to this latter view, the reader should be aware, that some metals combine with

* xiii.—4.—ii. The description of this treeless tract, with its burnt ashy surface, and its three upswelling craters (τρεις φυσαι), is very graphic, and might have been taken from Auvergne.

† Travels in Asia Minor.

‡ Dr. Daubeny, on this supposition, traces out in sequence all the principal *chemical* phenomena of volcanoes.

§ Mallet, in Reports to Brit. Assoc.

oxygen only between certain ranges of temperature and part with it at higher ranges. They may also be reminded of a beautiful phenomenon in the cooling of silver refined from lead. When the last breath of the bellows has ceased, and the silver, pure and white, gradually cools, so that the surface becomes coherent and seems to be solid, a sudden escape of gas takes place, the crust is opened and upheaved, a shower of silver is scattered about, many small craters appear, and the silver plate is like the moon, or like what a volcanic region may be supposed to have been after the first eruption. The gas is oxygen. It is conceivable that water might be conducted, in consequence of some accident of the earth's crust, to the required contact with the liquid lava, at some moderate depth below the surface, and thus high pressure steam be generated and accumulated until an eruption comes. But a gaseous force of some kind must be supposed. Thus may the melted rock be pressed up to the very summit of the Teneriffe and the Andes, and masses of stone, 8 lbs. in weight, be hurled out of Vesuvius, so as to fall at a distance of five or six miles at Pompeii. In the case just mentioned, it is necessary to suppose the stone to have been thrown about 7,000 feet above the summit of Vesuvius, or more than two miles above the sea, and the force to do this may be supposed to have been seated one, two, or three miles below.

That the steam or gas power, thus estimated for intensity, is also of enormous volume and magnitude, appears from the continuity of some eruptions, the amazing mass of rock which has been ejected, the clouds of ashes, the rapidly formed hills, the land upheaved, and the islands raised. Thus in 48 hours the volcanic forces seated about the Lucrine lake raised by showers of ashes a hill called Monte Nuovo, 440 feet high, and 841 feet deep in the middle (1538). And Skaptar Jokul, a great Icelandic volcano, threw out three streams of lava, eight miles apart, which covered 1,200 square miles.

The pressure of steam equal to raise felspathic lava 5 miles, may be called in round numbers 2,000 atmospheres, a pressure quite conceivable, though seldom attempted by mechanicians till lately, at the request of the British Association, by Mr. Hopkins and Mr. Fairbairn. These experimentalists have accumulated pressures equal to that of the highest mountains—nay, equal to 33 miles of water. Such a pressure, unrelieved by volcanic vents, might lift large tracts of solid land—probably does so—probably did so on the western coast of South America in 1822, when, for 1,000 miles in length, the level of land and sea was altered, and in many places the ground was permanently raised.

In harmony with the view here proposed—the dependence of volcanic excitement on extrication of elastic vapour—we find the greater number of active volcanoes situated along the margin of the sea, or

in islands. Thus the long range of the Cordillera of the Andes—the Aleutian and Kamskatchan volcanoes—the active and extinct vents of the African and West Indian Islands, Iceland, Sicily, Vesuvius—all favour the hypothesis. Even the long extinct volcanoes of Auvergne, the Eifel, and Hungary, are situated near old lakes of considerable extent, or valleys, once occupied by broad arms and gulfs of the sea.

Volcanic vents presuppose a fracture of the earth's crust; when they range in lines, it is on the lines of continuous fissures; when they form insolated groups, it is in a country where the strata have been shaken and broken by limited or confused dislocations. In this respect the modern volcanic rocks are like those of earlier date; they appear along the lines of fracture, made for them by preceding subterranean disturbances. It is probably in consequence of such disturbances, in other situations, that the sea water obtains access to the roots of volcanoes, and converts a sleeping lake of lava to a boiling, bursting, and exploding caldron.

We arrive then, by the contemplation of volcanoes, at a general idea of the condition of the earth's interior. It would appear that far below the rocks we are acquainted with, at a depth of some miles, say ten, parts of the earth are still fluid with heat. As these parts, to judge from what comes up to the surface, are not identical, we may admit that the several volcanic systems are founded on several and separate lakes of molten rock. Each of these is subject to excitement, or allowed to sink to rest, under conditions apparently separate for each, though, perhaps, really dependent on one general condition—a condition which at uncertain intervals, and at undetermined places, breaks up the solid framework of the earth. What may such a condition be? Before assuming it, we must inquire into the theory of earthquakes.

370 Bourbon.

Earthquakes.

Far removed as are the British islands from the seats of now active volcanoes—and though, to judge by the evidence of plutonic rocks, no strictly volcanic phenomenon has been manifested here since tertiary periods—we experience from time to time with a considerable force the shocks of earthquakes derived from other regions. We may by processes of tabular comparison occasionally discover the volcanic system on which they seem to depend; more rarely the local eruption which sometimes relieves the general tremor. While particular tracts, as Teneriffe, enjoy comparative freedom from the earthquake, in consequence of the perpetual operation of the volcano, "with its mountain torch"—other regions, like Asia Minor, are much shaken where once the subterranean fire was formerly manifested—and the ground is permanently displaced in other districts, like Cutch, very far removed from the sight of ignivomous mountains. The earthquake is both earlier and later than the eruption, and the ground is disturbed even far beyond the probable extent of a particular volcanic area.

Dr. Daubeny regards the primary shock of an earthquake as the result of local volcanic excitement, evidence of the accumulation and elastic pressure of imprisoned gases; the propagation of the motion to be due to vibration in the mass of the rocks. To complete this view, we have to inquire what brings the water, which feeds the fire and ministers to the fury of volcanoes, to its place in the subterranean laboratory. The answer must necessarily be, fissures in the rocks. But such fissures are occasioned by, and are the evidence of, earlier convulsive movements. If we seek the cause of them, we certainly find the greater part of the necessary evidence in the innumerable fractures and flexures of the earth's crust, of every geological date, by which most extraordinary disturbances of the strata have happened; and these very frequently, and in very large areas, where no other evidence of contemporaneous volcanic excitement can be discovered. It follows obviously that many movements of the earth's crust have been excited without the immediately preceding or coincident local agency of volcanoes; movements so great, in a vertical sense, so extended horizontally, and so limited in time, as to suggest nothing less than a general force, in which all the *differential* effects of volcanoes should be *integrated* into one energetic reaction of the interior of a heated and partially fluid planet against the cooled and consolidated exterior crust.*

According to the comprehensive idea of Darwin, earthquakes and volcanic eruptions originate in some local fracture and displacement

* Humboldt's definition of volcanic agency, in "Kosmos," contains this comprehensive view.

of the bed of the neighbouring ocean; the volcanic effect—the awakening of the half-sleeping giant of fire—spreads as far as the subterranean sea of molten rock extends, but is excited to violence at one or more points, the most favourably circumstanced at the time; the convulsive movement is propagated through the solid and liquid contents of the crust of the earth, as far as the nature of these materials and the force of the blow permit. It is important to remark that a blow is struck—the earthquake is the evidence—and this can only mean some rending of the solid crust of the earth. Thus a convulsion seems the necessary precursor of the earthquake; and to allow of the movement traversing whole continents, we must suppose the blow to be given at a considerable depth (expressed in miles for example) below the surface.* What can be the agency of such a blow? How is the tremor propagated?

Mitchell † entertained the idea that the sheet of rocks, constituting what we know of the crust of the earth, was flexible enough to bend to the agitation of an interior liquid ocean of melted rock. The earthquake in this view is a wave in the rocks representing a tide in the subjacent fluid. Rogers ‡ supposes waves of this kind, moving parallel to certain axes, to be effective in permanently raising the ground; and attributes to such an agency in early geological periods the formation of the anticlinal and synclinal hollows parallel to the Appalachian chain. Mallet, § however, both by reasoning and experiment, has shown that the earthquake movement is a wave of elastic compression, whose rate of movement varies according to the elasticity of the medium, the continuity of the rocky masses. There is one rate of movement for the sea, another for the land; one rate for solid granite, another for broken granite, another for loose sand. This movement, near the surface, is far less rapid than the elasticity of the media might lead us to expect; a fact certainly dependent on the many fissures of the rock, at each of which discontinuity and loss of motion are occasioned.

The actual velocities of some earthquake movements have been approximately ascertained as under in a line directly across the wave:—

		Miles per Minute.	Authority.
Conception, earthquake,	1835	30	Rogers, Rep. to Brit. Assoc. 1843.
Guadaloupe,	1843	27	Do. do.

The velocities, as usually stated, not being reduced so as to express the progress of the wave at right angles to its crest, are not available

* Stukeley assigned the improbable depth of 200 miles for the forces of an earthquake in Asia Minor, A.D. 17, which embraced a circle of 300 miles in diameter.

† Phil. Trans., 1760.

‡ Brit. Assoc. Reports, 1843.

§ Mem. Royal Irish Acad., 1846. Brit. Assoc. Reports, 1850. Et seq. ann.

in such statements. The Conception earthquake had its crest directed N.N.E. from the western border of Alabama to Cincinnati, a distance of 500 miles. On this line it was felt simultaneously. The motion was to the E.S.E., and was felt at successive times simultaneously on lines directed to the N.N.E. If a measure of velocity were taken on the N.N.E. line, it would appear infinite; on the E.S.E. line, 30 miles a minute; on intermediate courses, intermediate velocities. The *apparent* velocity of the wave at the surface will be greatest near the point vertically situated over the disturbance.*

Mr. Mallet,† by careful experiments on the sands at Kingstown, and in the granite rocks at Dalkey, obtained velocities of wave transit as under:—

	Feet per Second.	Miles per Hour.
Loose sand, Killiney	825	9½
Solid granite, Dalkey	1,306	15
Fissured granite, do.	1,665	19

In these cases at the surface the velocity is somewhat greater or somewhat less than that of sound in air, but very far less than was expected by the ingenious author, from his knowledge of the elasticity of stony media. To judge by experiments on their elasticity, we might expect the sound wave to travel—

	Feet in a Second.		Feet in a Second.
In air	1,140	In primary limestone	6,696
— water	4,700	— carboniferous limestone	7,075
— lias	3,640	— hard slate	12,757
— coal sandstone	5,248	— granite perhaps still higher rate.	
— oolite	5,723		

And it is supposed the earthquake wave of elastic compression would travel at nearly the same rate.

According to Mallet, the depth of the point where the blow or concussion which is at the origin of earthquake movements takes place may be placed as far down below the surface as the versed sine of the arc cut off by the extreme points of the space subject to tremor. In some cases this passes very deeply into the earth, *very far below the utmost probable depth of volcanic excitement.* Taking into account all the phenomena of earthquakes, this author admits for consideration the following modes of origin of the impulse ‡:—

The operation of steam extricated by cooling from the spheroidal state.

Evolution of steam through fissures, and its irregular condensation under pressure of sea water.

Great fractures and dislocations in the earth's crust, suddenly produced by pressure in any direction.

Recoil from volcanic explosions.

* Hopkins' Brit. Assoc. Reports, 1847. † Mallet, Rep. to Brit. Assoc., 1851-1852.
‡ Reports of Brit. Assoc., 1850.

In cases where the energy has been excited at a depth of many miles, the most probable cause seems to be the third, viz. the dislocation of the solid masses of the earth's crust. We may, therefore, consistently ask what may be the thickness of this crust?

Thickness of the Crust of the Earth.

Geological observation teaches us that solid rocks exist about the surface of the earth, the thickness of which added together would equal a few—say ten—miles. But we cannot be sure that to even that depth they retain solidity. In the truly volcanic districts this seems not to be the case. In these districts, at least, lakes of melted rock exist at probably a smaller depth.

Researches of another kind, by teaching us the rate of augmentation of heat as we descend into the earth, add something more to our means of estimating the fluid or solid condition of its interior masses.

By experiments in mines, and collieries, and deep wells, it is found everywhere that the variable influence of the seasons on the temperature of the earth becomes insensible at a small depth (60 to 100 feet); and that below this depth the heat continually augments by a sensible and nearly uniform rate. In the mines of Cornwall this rate is usually about one degree of Fahrenheit in 45 feet of descent, there being some difference between the slaty rock, called killas, and the granite. In the collieries of England the augmentation is less rapid, one degree for 60 feet being a general mean. In Artesian wells very similar results obtain. There is no doubt that these results are independent of merely local volcanic excitement, chemical actions, and pressure of matter. They depend on the proper interior temperature of the earth, the residue of its original heat. This residual heat is still slowly wasting away, so slowly, however, as hardly to affect the temperature of the surface more than by a small fraction of a degree.

From these geothermal researches we find that at a depth of 8 to 12 miles the temperature is probably about 1,000°, high enough to melt some of the more fusible rocks, and at 20 or 30 miles* 2,000° or 3,000°—a heat at which few substances could remain solid, unless an obstacle to fusion be caused by the augmented pressure experienced at such depths. Such an effect pressure really produces. It augments the necessary temperature of fusion in a solid, and of ebullition in a liquid; but we do not yet know enough of the limits and measure of its effect to be able to say to what depth downward it would propagate solidity in a fluid which was covered by a refrigerated crust.

* The depth assumed in M. Bischoff's Theory of Volcanoes.

There is, however, yet one more process for discovering the depth of the solid crust of the earth—a mathematical analysis of those planetary peculiarities which depend on the earth's external form and internal constitution. Of these the precession of the equinoxes, a phenomenon depending on the attractions of the sun and moon on the spheroidal surface of our rotating planet, has been made the subject of a celebrated memoir by Mr. Hopkins.* Assuming, with the consent of all astronomers and mathematicians who have considered the subject, the former fluidity of the earth, its actual rotation, and the attractions among its particles, the oblate spheroidal figure of the earth is a necessary consequence, and the elliptical character thus imparted to the surface is repeated in all parts of the interior; so that, the density increasing with the pressure toward the centre on every radius, the interior surfaces of equal pressure and equal density are also concentric and spheroidal, and have their axes in the axis of rotation. This result is found to agree with the experimental measures of the earth's mean density and the density at the surface, with certain inequalities in the moon's motion, and with the phenomena of precession of the equinoxes and nutation of the earth's axis.

The primeval spheroid of fusion, above referred to, being subject to cooling at the surface and to pressure in the interior, may, if pressure be an unimportant cause of solidification, consist of a solid external shell and an interior mass, growing more and more fluid to the centre, a frequent hypothesis in geology. But, if pressure be a very important agent of consolidation, its increase toward the centre may cause solidification there, while the surface grows solid by cooling; and thus there may be a solid crust and a solid central mass, with an intermediate fluid zone. Or, thirdly, these processes may have proceeded so far as to make the whole globe solid. To decide which of these conditions is the true one, Mr. Hopkins investigated the effect on precession and nutation of different assumed conditions for the interior, and found that the amount of these motions depended on the difference between the ellipticities of the external and internal surfaces of the crust and on its thickness, and finally determined the necessary least thickness of the crust to correspond with the present observed amount of precession. This thickness is not less than *one-fourth or one-fifth of the radius* of its external surface. The earth, then, appears to be solid, or to contain principally solid parts, for 800 or 1,000 miles in depth from the surface.† That it is not universally solid the floods of melted rock which occasionally rush out of volcanoes sufficiently prove. The subterranean oceans of lava which feed these vents are probably limited and detached in separate

* Phil. Trans., 1839, 1840, 1842.

† A later analyst, Mr. Hennessey, assigns a less depth, but still one greatly exceeding the conjecture of Bischoff and many geologists.

systems. Combining these facts with the general conclusion of Mr. Hopkins, we see clearly that solidification has proceeded downward from the surface far enough to reduce to large insulated patches all the fluid matter near to the surface, or capable of being raised to it. Hence the separate and independent periods and circumstances of excitement in separate volcanic districts; the perpetual smoke of one mountain, the long extinction of another; the fulness and continual ebullition of one crater, the depression and falling in of another.

DISTURBANCES OF THE STRATA.*

The introductory observations in pp. 33 to 37 may serve as a foundation for the following inquiries into the effects and causes of subterranean convulsion; and the remarks in pp. 119, 221, 322, 444 may be read in connection with the preceding chapter. This great subject may be carefully considered in four divisions.

1. The geological periods of convulsion.
2. The direction of convulsive movements.
3. The effects of convulsions in altering the relations of land and water.
4. Effects on the deposition of strata and on organic life.

Geological Periods of Convulsion.

Proofs of.—In order that our statement of results on this important subject may be as much as possible free from objection, it will be convenient to begin by fixing what phenomena are to be taken as proof of the occurrence of convulsions, and what method is to be followed in assigning their place in the scale of geological epochs. When strata, originally level, or nearly so, have been raised to high angles of inclination; when beds, originally continuous, are found to be broken asunder, and their separated portions placed in new relations of position, one portion being raised or depressed, or both deranged; when layers, originally plane, are found to be bent into extraordinary curvatures; in all these cases the conclusion is immediate, that convulsions have happened in the very points where such phenomena occur. The only question which can arise, supposing the actual position of the rocks well ascertained, respects the certainty of our postulate of their *former* position. Persons who have read old books, but have not studied natural phenomena in this point of view, may be apt to suppose that, under particular circumstances, strata may be formed at high angles of original inclination. Those

* The greater part of what follows in this chapter remains as it was written in 1832-4; time having in no sensible degree modified the reasoning. Since that date, De Beaumont has enlarged his speculations on great circle fractures, and Hopkins has developed various physical researches, and added much of clearness to geological dynamics.

who have looked more narrowly into the matter, and have been instructed by Yates's observations on the positions assumed by earthy materials falling in air and in water, may be led to extend the judiciously limited inferences of this author to cases where they will not apply. For very narrow areas, and in extremely troubled waters, the mountain torrents, or the surf of the ocean, tumultuous deposits of sand and pebbles happen, in which the laminæ may be inclined at considerable angles, and cover one another confusedly. On this account it seems not unnecessary to re-examine the basis of our argument, and see whether it will bear the weighty superstructure we design to lay upon it.

371 Island of Tahiti.

1. **Examination of the Basis of the Argument.**—General experience assures us of the general fact, that it is a characteristic effect of agitated water to deposit what sediment falls slowly from it in the form of strata whose upper surfaces continually tend to become horizontal. This is seen in inundations from a river, in shallow and ruffled lakes, and within the low-water margin of the sea. The form of the bottom influences the horizontality of the upper surfaces of the deposits in such a way, that where the bottom is like a pit, the stratified masses above are hollow on the faces; but these effects of the original inequality are rapidly obliterated by successive coats of sediment, all becoming more and more nearly horizontal.

2. In perfectly tranquil water, through which any fine sediment is equally diffused, the depth to which this will cover any part of the bed depends on the depth of the supernatant water, and on the *angle*

of rest in water of that kind of sediment. The *angle* of rest *in air* for earthy substances is about 45°.

3. If a river bring sediment into agitated water, this will deposit it in strata tending to become horizontal, but with a constant dependence upon the point where the river enters, such that, the quantity of sediment being there always accumulating, a general conical slope therefrom in all directions will modify the horizontality of the strata.

4. If a river bring sediment into calm water, or into water suddenly deepening, so that all its lower parts may be considered as calm, the conical slopes from the point where the river enters will be much more abrupt than in the former case, in a certain proportion to the

372 Pass (Andes).

calmness and depth of the water. This Mr. Yates finds to be the case in the deep lakes which receive the abundant sediment of the boisterous torrents of the Alps; and, in consequence, we are furnished with a key which will ultimately open many curious results in the arrangement of sedimentary deposits. (See p. 482.)

On considering these cases with reference to stratified rocks, it is evident that instances coming within the class of conical deposits radiating round a point can only be of very limited occurrence, not likely to affect a general argument, and are, in fact, almost unknown. The estuary deposit of the Weald of Sussex shows no such structure; it cannot be traced in the Yorkshire estuary coal field; nor is there any mention of it in any lacustrine deposit which has been desiccated and exposed to our observation. It is very doubtful whether it can be recognized in any marine formation, and certainly it does not

clearly apply to any class of marine deposits now in progress: at the same time we must admit that, in all cases, the action of the sea growing less and less sensible far from shore where the water deepens, the sediment brought by rivers and floods must be formed in attenuated masses, thickest towards the shores. This effect will be evident in exact proportion to the *falling velocity* of the particles in water, so that pebble beaches may lie in steeper slopes, and cover shorter breadths than sands, while fine clays will spread farther into deeper water. (See p. 488.) But all these slopes *in water* are very gradual, so that even against the rocky eastern coasts of England, the deep waters have been filled up by sediments, which now assume a gently declining surface under the water, and a moderate slope above it.

Convulsions, Direct Proofs of Local.—For all the purposes of our present course of argument we shall therefore assume the law of original horizontality, or very moderate declination of the planes of *widely extended strata*, as amply supported by every needful proof from careful and scrupulous observation. Hence from adequate observations of the position of strata we can tell whether they have been altered in position or not by convulsions operating in those situations precisely.

Indications of.—Another class of appearances indirectly marks the effect of convulsion, either on the spot or at some distant point. When we find traces of a sudden and complete change in the whole course of the aqueous deposits, so that the quiet deposition of argillaceous or calcareous strata is interrupted and preceded by a tumultuous aggregation of pebbles, we know that there has been some access of agitation to the water. This may, according to circumstances, have happened from a periodical or accidental change in the drainage of the neighbouring land, or from some extensive change of the relations of land and sea. The latter cause may be reasonably adopted, provided that we find these indications of agitation very extensive, and provided that in some instances there be proof of the formation of local conglomerates following upon local convulsions. The latter requirement is found to be satisfied in many instances, and of the former it is easy to judge. One more indication of some distant convulsion affecting the relations of land and sea seems to be afforded from the rare case of the occurrence of one bed of marine shells among a vast abundance of fresh water estuary deposits (see p. 183), without any local unconformity of stratification.

Such are the phenomena to be taken as proofs of convulsion: the most important are those which distinctly establish the precise localities of the disturbance. Let us now examine into the mode of argument by which the geological epochs of these disturbances are to be established.

Epochs of, how Determined.—In all investigations concerning the

period when an event happened, we may consider the result completely obtained, when the limits of maximum and minimum antiquity are known as precisely as the data allow. In geological inquiries, the answer is always expressed in terms of the scale of relative antiquity of the stratified rocks, and a convulsion is fixed in geological time, when it can be shown to have happened after the deposition of one stratum, and before the deposition of another. If the strata which thus limit the period of the convulsion be consecutive terms of the series of deposits, the most precise attainable result is obtained; but if these limiting strata be not consecutive, the age of the dislocation is known only within a given range. An example of accurate determination of the geological era of a convulsion is afforded in the north of England, where the newest of the coal strata are found to be dislocated under the oldest red sandstones of the permian system. Instances of less precise determinations are common enough: for example, in the Mendip hills the dislocated mountain limestone is covered by undisturbed oolite, and, as far as this observation goes, the convulsion may have happened during any part of the long period occupied in producing the coal, red marl, and lias strata. In this case, however, by tracing the line of the dislocation to other localities, other strata are found to be so related to the limestone, as to fix the geological date of its disturbance within narrower limits.

If the dislocated strata be not actually seen covered by others which are undisturbed, another set of data must be employed. It may happen that around the disturbed rocks some newer stratum spreads in such a manner as to give sufficient reason to conclude that it was deposited since the period of the convulsion. This is, in most parts, all that can be observed with respect to the red marl around Charnwood forest, and it would be satisfactory evidence that the slaty rocks of that district were upraised before the period of the new red sandstone; and, in fact, we have found instances where the red marl does really cover with level beds the broken edges of slate.

If no horizontal or undisturbed strata be visible in any part of the dislocated tract, either in superposition or in juxtaposition, the limit of least antiquity vanishes, and we are in danger of imagining too modern a date for the convulsion; if the newer members of the dislocated group of strata be concealed, there is danger of ascribing too high an antiquity to the convulsion. It will be prudent to exclude all such cases from the argument: the others seem to be unobjectionable.

Question as to their Duration.—There is yet another point of view of much importance to the following investigations. What we have termed the limit of greatest antiquity marks clearly the completion of the convulsion; but the progress of geological inferences has brought us to the point of requiring information whether the dis-

turbances were very rapidly effected by one or a few sudden and violent efforts, or operated slowly by small and graduated movements. According to the former view, the whole amount of the dislocation was effected in so short a time that this may be regarded as nothing compared to the long periods occupied in the deposition of the strata; according to the latter, the disturbing agency might be at work during the whole, or some long part of the period of the formation of the dislocated strata, but ceased when their formation was complete. This is not a mere subtilty or needless refinement, it is very important to know which is the true doctrine: we believe it can be ascertained, for all instances where the facts can be clearly known; and though it would be premature to make any exclusive assertion, the general process of nature may be satisfactorily inferred.

Faults.—Proceeding from the clearest indications on this subject towards those which are less easily interpreted, we may remark, in the first place, that those dislocations commonly known by the name of "faults" in the strata (p. 34), which break the continuity of the beds along a certain plane or fissure, and elevate or depress one side, plainly declare themselves to be the result of single convulsive movements. To be satisfied of this, it is quite enough to contemplate diagrams of the effects (figs. 8, 9, 10, 11, pp. 34, 35); but actual inspection of the phenomena will leave no room for doubt that the whole mass of dislocated strata was put into its present relations, not by a repetition of small and gradual movements, but by sudden and violent agency. A repetition of small movements through the whole vast thickness of strata could not fail to break down those clearly defined walls of the fissure which so generally exist, especially among the harder rocks, and leave the fissure filled up with a confused aggregation of all the substances on its sides, instead of a clear space for the subsequent admission of sparry and metallic matter, or regular traces of the movement of these faces on each other.

The extent of dislocation to which the name of fault accurately applies is extremely various, the difference of level thus occasioned being sometimes a few inches, in many 100 feet, in others as much as 1,000 yards. This makes no difference in the argument, but it serves to mark out in very clear characters the degree of force exerted in each case. It is remarkable that those dislocations which make the greatest difference of level, range through the greatest lengths of country; so that the ninety fathom dike, so named from the observed extent of its dislocation, ranges from the eastern sea across the whole breadth of Northumberland, and certain dislocations in Yorkshire have ranges of ten, twenty, and thirty miles in one nearly straight line.

Great Dislocations.—As far as we know, the greater portion of the convulsive movements, whose production we are now investigating,

were accomplished by means of "faults." There are some very extensive dislocations which usually receive, and may perhaps deserve the same epithet, but which, for the purposes of our present argument, wear a somewhat different aspect. One of the most magnificent examples of dislocation in Europe is that grand break nearly along the line of the western border of Durham and Yorkshire, from near Brampton by Brough and Kirkby Stephen to near Kirkby Lonsdale, the effect of which is to throw down to the west, relatively, the strata of the carboniferous system more than 1,000 yards through a length of 70 miles. An axis of slate rocks rises along the line of fracture, which is also partially marked by dikes of greenstone. On the west the beds dip at high angles to the west; on the east they decline gently to the east. No proper plane of fault is traceable in this case of enormous disruption, owing to the circumstances of the country, and we must have recourse to other considerations to arrive at satisfactory inferences concerning the time employed in producing it.

In the first place we may remark, that this line of disturbance is cut off to the north by the ninety fathom dike, and to the south by the Craven fault; and there is every probability that it is actually continued along the lines of these faults to a direction right angled, or nearly so, to its own course. If this be so, and the whole is one complex dislocation, we may surely conclude that the middle portion, even if not of the same age as the extremes, was produced in the same manner.

Relation of Faults to Axes of Convulsion.—Again, the numerous faults of an ordinary character which cross the country in all directions between these great lines of convulsion, seem evidently related to and dependent upon them; a remark which receives corroboration from many other parallel inquiries. Amongst these faults it is possible, perhaps, to distinguish two periods of disturbance, the older one marked by a direction nearly east and west, which is that of most of the metalliferous veins, the other by a direction from north to south, which is that of several whin dikes, and some few lead veins. Perhaps these different directions may have taken their rise from the two directions of the axes of convulsion which bound the district.

The connection, however, is sufficiently clear to warrant our applying to those great axes of disturbance the limits of time by which the lesser faults are defined; that is to say, in many instances nearly coincident with the limits of uppermost coal measures and variegated new red sandstone.

Inferences.—It is apparent, therefore, that the evidence which can be collected on the subject of the simple dislocation of the planes of the strata, points to violent internal movement, occupying short

periods of time for the accomplishment of the phenomena. There seems to be no mark whatever of gradual or many times repeated efforts.

Some cases of disturbance, however, are of a complicated nature, and may probably be found upon further examination to require the admission of another order or another stage of violent movements and pressures. Such are the extraordinary retroflexures of the calcareous strata adjoining the Alps, the retroverted dips in the coal fields of Somersetshire and Belgium, and the flanks of the Malvern hills.

In some of these cases, as on the western side of the Malverns, and the western side of the Appalachian chain, we find the curvature often repeated on many synclinals and anticlinals; we see the slopes on each anticlinal steeper on one (the western) side; and we remark, in the anticlinals taken successively from east to west, that they grow less and less steep, and more and more broad, as we proceed farther and farther from the mountain chain.

What are usually called anticlinal axes of elevation, must, indeed, be considered as yielding insufficient evidence concerning the length of time elapsed from the beginning to the end of the disturbance. In some cases, indeed, the dips on either side from the axis are so steep that they seem to refer themselves to single and violent movements, but where, as in the Weald of Sussex, the appearances along the axis indicate that there the disturbance has been moderate, while toward the sides it has been extreme, the breadth of the country being considerable, there seems on a first view no very good reason for coming to a decision at all, as to the prolonged or transitory nature of the convulsive agency.

There is, however, an indication worth pointing out for the future guidance of observers on this branch of the inquiry. If we imagine that during the deposition of any class of strata, an anticlinal axis is formed so that they are gradually uplifted and converted to dry land, we may be sure that all the strata would be found to grow continually thinner from either side toward the axis of elevation, at which line they would become evanescent. Very few instances can be quoted where many strata are actually seen to be continuous over the anticlinal line. The Isle of Wight, the elevation valley of Woolhope, the Hampshire and Wiltshire chalk, and some remarkable cases in Switzerland, seem to be, however, sufficiently in point, and no traces of such a diminution are there observable.

General Conclusion.—Upon the whole, then, there is, for the most part, a want of proof that the disturbing forces were exerted through long periods beneath a given region, so as by many small and repeated convulsions, all operating in the same direction, to give the effect of one great dislocation. On the contrary, we may believe,

that the time was very limited during which several of the great dislocations and axes of disturbance assumed their respective characters. Yet, owing to the difficulty of the investigation, the question must in many instances be left wholly undecided.

The following table shows the geological periods of many remarkable convulsions in Great Britain, and the places where some of the most considerable effects are manifested :—

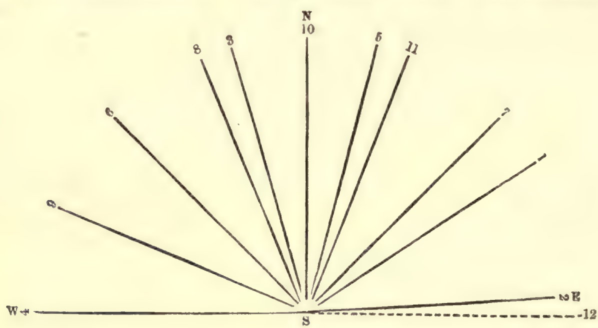
No. Geological period of the convulsions.	Effects noted.	Localities of some of the phenomena.
a. During the deposition of the slate system	Production of conglomerates.	Derwent Water, Cumberland, North Wales.
b. Ditto	Porphyry and greenstone and trappean conglomerates ...	Grasmere in Westmoreland, Radnorshire, Merionydd, &c.
I.—After the Silurian strata and before the carboniferous system	Disturbed position of primary rocks	The Grampians, Lammermuirs, Cumbrian mountains, North Wales.
c.	Production of old red conglomerates	The Highland Border, Cumbria, &c.
1. During the carboniferous period	Marine bed among estuary deposits	Yorkshire.
II.—Before the adjacent rocks of the Permian system taken generally	Numerous dislocations, fissures of dikes and veins, anticlinal axes, &c........	In all coal districts of this era, both in Europe and America. Charnwood, Crossfell fault.
d. During the Permian period?	Production of conglomerates.	North of England, north of Germany.
III.—After the earlier Permian period?	Veins of lead, &c., Great or 90-fathom dike	Yorkshire, Pontefract, Mendip hills, Tynemouth castle, border of Cumbrian group (Kirkby Stephen).
e. After the later Permian period..................	Production of new red conglomerates	North of England.
? During the oolitic period?	Unconformity. Kelloways rock in contact with the lower oolite group excluding the upper portion......	Cave, Yorkshire.
IV.—After the oolitic period.	Unconformity of strata between oolitic and chalk systems.....................	Yorkshire wolds, Dorsetshire cliffs.
2.	Estuary deposits. Pebble beds of lower green sand ..	Wealds of Kent and Sussex, Lincolnshire, Isle of Wight, &c.
During the chalk period?..	?	
f. After the chalk period ..	Pebble beds, wasted surface of chalk..................	Hertfordshire, Vale of Thames.
V.—After the Eocene deposits..	Vertical strata.................	Isle of Wight.
3.	Marine deposits between lacustrine beds	Ditto.
g.	The crag	Essex and Norfolk.

The Roman numerals are applied in the above list to all periods where considerable movements are traced in direct effects of dislocation and unconformity ; italic numerals to those cases where a change in the nature of the water over given regions seems to result from a distant convulsion ; and small letters to mark the occurrence of the most remarkable periods of conglomerates.

The next table presents the results of a more extended survey of direct convulsive effects on the continent and islands of Europe, as they appeared to E. de Beaumont on the first proposal of his ingenious views of subterranean movement :—

No.	Geological period of the convulsions.	Effects noted.	Localities of some of the phenomena.
I.	(1 and 2, E. de B.)—Before the old red sandstone....	Anticlinal axes and great faults of the slate system..	The Hunsdrück and Taunus.
II.	(3, 4, 5, E. de B.)—*a.* Before the rothetodteliegende..................	Immense disruptions and faults of the coal system...	Calvados, south-west border of the Vosges.
	b. Before the zechstein....	Immense dislocations and faults of coal strata.........	Westphalia, Belgium.
	c. Before the new red sandstone..................	Immense dislocations and faults......................	Vosges, and Black Forest.
III.	(6, E. de B.)—Before the lias.....................	Mountain ridges of zechstein, &c......................	Thuringerwald and Böhmerwald.
IV.	(7, E. de B.)—Before the lower green sand........	Abrupt and distorted strata of oolitic system...........	Mont Pilat, Cevennes (perhaps the Erzgebirge).
V.	(8, E. de B.)—Before the uppermost chalk beds...	Abrupt elevations of green sand and lower chalk......	Mont Viso, Devolny.
VI.	(9, E. de B.)—Before all the tertiary rocks.......	Elevations of chalk and green sand......................	Pyrenees, Northern Apennines, the Morea.
VII.	(10, E. de B.)—Before the nagelflue................	Detached ridges............	Corsica, Sardinia, Auvergne.
VIII.	(11, E. de B.)—Before some diluvial beds.......	Newest tertiaries uplifted....	The range of the Western Alps, Diablerets, Mont Blanc.
IX.	(12, E. de B.)—During the formation of other diluvial beds................	Some diluvial beds convulsed	The range of the Eastern Alps from the Valais to Austria.

Elie de Beaumont's Generalizations.—It is to M. Elie de Beaumont that we owe the impulse which the study of the periods of geological disturbance has received, and he is the principal authority for the construction of the preceding table. M. de Beaumont



373 E. De Beaumont's System of Elevations.

1 Snowdon.
2 Ballons, Bocage.
3 Crossfell.
4 Pays Bas.
5 Rhine.
6 S.W. of Brittany.
7 M. Pilas, &c.
8 M. Viso.
9 Pyrenæo-Apennine.
10 Corsica.
11 W. Alps.
12 Alps.

makes twelve distinct systems of convulsions which are supposed to have happened at as many distinct periods, but we do not find sufficient evidence to substantiate the division into five systems, of the first and second of our table. The following is De Beaumont's view of these five systems, including applications in Great Britain for comparison with the details of our first and second groups :—

No.	Geological period of the convulsions.	Effects noted.	Localities of some of the phenomena.
I.	1. During the deposition of the lower Palæozoic strata, anterior to upper Silurians...	Elevation of mountain chains	Snowdon, Anglesea.
	2. Posterior to the upper Silurians, anterior to old red sandstone...	Great faults, and anticlinals.	Grampians, Lammermuirs, Cumbrians.
II.	3. After the coal strata and before rothetodteliegende	Immense disruptions and faults of the coal..........	From Derbyshire to Northumberland along the Western border of Yorkshire, Malvern.
	4. After the coal strata, and before the zechstein...............	Ditto......................	Westphalia, Belgium, Mendip, South Wales.
	5. After the coal strata, and before the bünter sandstein........	Great disruptions............	Vosges and Black Forest, from Basle to Mayence Faults in magnesian limestone of northern counties.

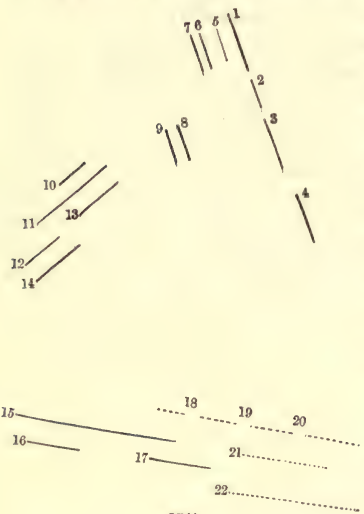
Direction of Convulsive Movements.

Elie de Beaumont's Hypothesis.—It is impossible to make many observations concerning faults and other dislocations of the strata, without being strongly impressed by the fact that they commonly follow certain straight lines through a country, everywhere producing analogous mechanical movements. The length of their courses is often so considerable that one great dislocation defines the physical geography of a district. It has been long known that in mining countries the faults take parallel directions, and sometimes two or more systems of dislocations, crossing in certain angles, were found to be of different antiquity. That dislocations were in some respects to be compared to the effects of earthquakes was also well understood, but no one before De Beaumont appears to have carried his notions of the coincidence between the lines of convulsion and the direction of the great physical features of the globe, so far as to venture on the construction of a general system. This excellent geologist believes that there is a constant dependence between the direction of the dislocation, and the geological epoch of its occurrence, such that all the dislocations of the same age are parallel to one and the same great circle of the sphere; and that, *in most instances*, dislocations of different ages are parallel to different great circles which intersect one another at assignable angles.

How to be Examined and Tested.—It will be readily understood that this general hypothesis is not to be tested by single or small dislocations. It must be examined on a great scale, by means of very exact and numerous data. It is not too much to assert, that in the present state of geology, the facts known are not clear and numerous enough to support this hypothesis; and on the other hand there are not facts to warrant the unconditional rejection of it. It must be looked upon as a first attempt in a new field, as a generalization carried to extreme; but it is certainly founded on important data, and in several instances agrees well with observation. The

principal difficulty of applying satisfactory tests to its consequences, arises from the uncertainty of the exact date of many of the most characteristic convulsions. We cannot positively tell whether the dislocations of the Grampians and Lammermuirs, which take parallel courses, were geologically synchronous or not, because the beds dislocated are not the same. Even in the case of the great faults which followed upon the carboniferous system, the limits of the geological epochs of their occurrence are often too vague for the application of such a theory. Rothetodteliegende and magnesian limestone cover unconformably the coal of the north of England, and thus define the date of the convulsions; but in the south of England these are of rarer and less regular occurrence, and often entirely wanting, and then the new red sandstone above the coal gives only a vague approximation to geological time.

At present these are irremovable difficulties. We can, then, with strict propriety, only examine the question of the dependence of the direction of dislocations on the geological period, by comparing together, first, the directions of those dislocations which are *not* known to be of different ages; and second, of those dislocations which *are* known to be of different ages.



374*

The subjoined diagram (fig. 374) is intended to show the directions of three of the great movements of strata in Britain which appear to be grouped in traceable systems.

The earliest in the catalogue is that N.E. and S.W. system which includes Snowdonia and a large tract about it. By this the Cambrian strata, as understood by Sedgwick (including the lower silurian of Murchison), have been much disturbed in North Wales, so that unconformity appears between them and the lower part of the upper silurians.

* 374 Three Systems of Subterranean Movement in Britain.

1 Clyde.	6 Nith.	11 Snowdon.	15 South Wales.	19 Highclere.
2 Eden.	7 Ken.	12 Dolgelly.	16 North Devon.	20 Surrey.
3 Ribble.	8 Dee.	13 Bala.	17 Mendip.	21 Sussex.
4 Derbyshire.	9 Clwydd.	14 Dyfi.	18 Wilts.	22 Isle of Wight.
5 Annan.	10 Menai.			

Another great system of movement is typified in the north of England by the great faults and anticlinals of the Pennine chain, varying from N.N.W. to S.S.E. Nearly parallel to this are the dales of the Nith and the Annan, the Dee, and the Clwydd. These dislocations precede the whole mesozoic system.

A third series of parallel or nearly parallel movements affects the south of Ireland, South Wales, and the south of England. In South Wales, the Mendip hills, and North Devon, it disturbs all the strata earlier than permian; and in the isles of Purbeck and Wight, and the weald of Sussex, it disturbs all the eocene strata. This appears a case of nearly the same direction, and nearly the same kind of movement (anticlinals and synclinals), affecting a given district in different geological times. The earlier movement was continued both eastward and westward farther than the later one, so as to embrace a length of fully 700 miles of the earth's surface—from Bantry Bay to Elberfeld. The later movement, though less extended in length, affected a large breadth of country—from the Isle of Wight to beyond the Thames valley.

More Limited Inquiry.—Relinquishing for the present any further attempt to construct a general system of relation between the age and direction of dislocations, we may still find it useful to inquire what laws of direction belong to dislocations in a limited district.

Hopkins's Theory of Elevation.—Mr. Hopkins has given a mathematical form to the experience of miners and geologists which had recognized the existence in a limited tract of two sets of dislocations often bearing metallic matters of different kinds—at right angles to one another. He shows by simple reasoning how these may depend on one system of movement under that district. Suppose, under the whole of a limited tract, an expansive force gradually augmenting, and capable of bearing up the whole mass of the strata there. Let these strata be capable of extension, so that they should swell up into an arch, but let their extensibility be limited, so that at last the arch must break. It will depend mainly on the outline or figure of the ground raised, what shall be the direction of the fractures. If the area be indefinitely very long as compared to the breadth, and the sides be parallel, there will be, in the first place, one or more fractures parallel to the length of the figure—across the lines of greatest extension—and, secondly, other fractures depending on them, at right angles to them. Thus, in the mining districts of Aldstone moor, the north and south fractures, parallel to the great Pennine fault, and the east and west fractures, at right angles to these, compose a system in accordance with the mechanical theory.

Again, if the force under a given district be determined by any peculiarity of the rocks to a conical elevation, there will be radiating primary fissures, and secondary concentric ones. Such a case, perhaps,

occurs in the volcanic elevation of Mont D'Or.* An elliptical elevation would have characters intermediate between the two, and the same district may show traces of one of these superadded to the narrow rectangular elevation first noticed.† Such a case occurs in the Weald of Sussex. By cautiously employing this ingenious mode of interpretation, we shall be able to determine in any given region where the fractures of the strata are well traced, not only what was the whole area of the ground subject to any movement, at a given time, but what part of that area was moved, by one definite force acting everywhere below it, in a certain characteristic manner.

The remarks already made, and in the section on mineral veins, will render it unnecessary here to quote examples in which Mr. Hopkins's views find a useful application. We will only state a single case of the parallelism of trap dikes, which has been furnished by Archdeacon Verschoyle, in the north-west part of Mayo and Sligo.‡ He describes no less than eleven basaltic and amygdaloidal dikes, which, in a space of 11½ miles in breadth, traverse the northern part of the district in a nearly east and west direction, and cut through all the formations from the gneiss to the carboniferous limestone. One of these dikes he traced between 60 and 70 miles, and believed it might be followed much farther to the eastward. Two of the dikes are crossed by others having a north and south direction.

Direction of the Strata.

Mitchell's Views.—It was long since remarked by Mitchell, that the direction of the strata in any region was generally parallel to the ranges of mountains; a truth of great importance in the modern system of geology. The prevalent range of the strata in any country must, however, depend partly upon another circumstance, *viz.* the original line of the ocean boundary. In many parts of the globe the most prevalent direction of the strata is observed to be north-east and south-west. Humboldt was so struck with these *loxodromic* lines in Europe, that he says one of his principal inducements to visit equinoctial America was to examine the directions of the strata there. He has furnished evidence that the parallelism of the strata to the great lines of mountains, is a general law of nature.

Necker's Inferences.—M. Necker, in a communication to the *Société d'Histoire Naturelle de Genève*, has shown a very unexpected coincidence over large portions of the northern hemisphere, of the direction of the strata, and the curves of equal magnetic intensity, as traced by Colonel Sabine. One of these curves, that of 297 seconds, traverses Scotland in a direction north-east and south-west, which is exactly that of the

* Mem. Geologiques, de la France.
† Cambr. Phil. Trans., 1837.
‡ Proceedings of the Geol. Soc., 1833.

strata; it keeps the same direction by Christiania in Norway, where, according to M. Von Buch's observations, the strata trend north-east and south-west, and passes through Sweden, where, according to Hisinger, the same direction of strata predominates. On arriving at the gulf of Bothnia the magnetic curve turns north-west and south-east, which, according to Strangways, is the direction of the southern border of the Swedish and Russian granite.

The curve of 308 seconds enters Europe by Lisbon, and passes south-west and north-east through the Spanish peninsula, which is nearly the line of most of the long Sierras between the great rivers; it passes by the Cevennes, and goes parallel to the Alps in their north-east course to the Tyrol, but there turns south-east, as do also the lines of stratification through Carniola, Istria, Croatia, Dalmatia, and the Morea. Parallel to these are the Carpathian mountains. The same correspondence between the magnetic curve and the lines of strata is traced through the Crimea and along the Caucasus.

In North America the magnetic curve and the stratification range north-east and south-west along the whole eastern coast; in the Rocky mountains both extend from north north-west to south south-east; in Mexico the magnetic curve takes the parallel of the Cordillera of Anahuac north-west and south-east, and ranges along the south coast of New Spain. Farther to the south the curves resume their course north-east and south-west, which, according to Humboldt, is the direction of the strata in Venezuela, and between the Orinoco and the Amazons. The mighty chain of the Himalaya, which in Nepaul bears north-west and south-east, and turns north-east at the north-east extremity of Bengal, is parallel to the curve of 297 seconds which was first noticed.

These remarkable accordances deserve the attention of geologists, who must always receive with particular gratification any results tending to connect the general facts of the construction of the crust of the earth with the laws of the distribution of terrestrial magnetism, electricity, and temperature.

Effects of Convulsions in altering the Relations of Land and Water.

The submarine origin of the whole stratified crust of the earth being admitted, and the actual elevation of the rocks above the sea in the existing continents being known, it is required to determine the several geological periods when different parts of the solid land were raised above the waves. It is usually taken for granted that this effect has been produced by the several systems of convulsions which have impressed angular movements upon dislocated portions near the surface of the earth, and thus raised some portions and, perhaps, depressed others. That this general impression is fre-

quently well founded, though it does not embrace the whole truth, will appear from the simple consideration, that the whole configuration of the dry land, whether in islands or continents, is dependent upon the direction and elevation of the chains and groups of mountains, which were certainly elevated, at various assignable geological epochs, above the ancient sea.

It may be asked how is this ascertained? The mere fact of those mountains being convulsed, and the strata therein thrown into angular positions, does not seem to prove that the region was elevated by such action above the level of the sea, nor, perhaps, that it was uplifted at all; since it may be imagined, with some theorists, that the neighbouring parts were depressed, and that the general level of the ocean has been lowered. In answer to this we may proceed to show that the effect of the convulsions was relatively to raise the convulsed parts; that these parts were in several instances elevated above the sea at assignable periods; and that these effects were independent of any imaginary depression of the general level of the ocean.

Elevation the Consequence of Convulsion.—That the effect of convulsions has been, generally, to raise the convulsed parts will appear by considering what is the focus of the disturbance and the direction of its energy. The mountain chains and groups are most certainly the foci of the disturbing forces; for as we pass towards them, from all sides the number and force of the dislocations continually increase, and the declination of the strata grows more and more violent. The direction of the disturbing force is by the same process of observation clearly discovered to be vertical or nearly so, and outwards from the central regions of the earth. It was an expansive force, which employed its principal efforts along certain lines and about certain centres, there breaking and bending the strata in the highest degree, but also lifting them up on all sides around. As far as we can judge, this elevation of the mountain chains and groups was generally unaccompanied by any neighbouring violent depression; for the inclination of the strata for the most part gradually subsides to a gentle slope, and finally vanishes in nearly horizontal planes. In the mountain chain itself various and suddenly reverted dips may be met with corresponding to the violence of the disruption, but by a careful study of the exterior slopes the general tendency of the convulsion may be clearly deciphered.

The same data will not, however, by any means give us right to conclude that the mountains so uplifted were raised above the sea, because, though we may know the absolute height of the vertical movement, this will avail us nothing in our ignorance of the original depth of the water. We must examine to see whether they bear on any part of their surface any traces of those later marine deposits

which spread around their bases. If they do, we may be sure they were not elevated above the sea till after the date of these strata; as, for instance, the Alps, which bear upon their crests portions of oolitic, cretaceous, and tertiary strata are thus proved to be of modern elevation. If they do not, and the newer marine strata around their bases have been deposited horizontally against the slopes of the mountains, we are entitled to believe that these had been previously reared above the sea. This conclusion, however, it must be always borne in mind, does not inform us correctly to what height they were reared above the sea, but leaves us to infer that they have since partaken of another movement by which these newer strata have been placed at their present elevation.

Speculations on the Ocean Level.—The facility of escape from many embarrassing considerations which a general depression of the level of the ocean seemed to offer was too tempting to speculators in geology to permit them to inquire into its physical probability. The simple question of what has become of the vanished water was disregarded by Werner, and perhaps never thought of by his followers. It will not now be sufficient to press it into a subterranean abyss, nor to carry it off to other planetary regions in the tail of a comet. We must admit that the quantity of water upon the globe has been constant, or give up all pretence to philosophical moderation; and with this restriction upon our inquiries it becomes easy to prove that the level of the ocean is confined within very narrow limits of fluctuation, so long as the earth's axis and rotatory velocity are supposed invariable. If the level of the ocean be expressed either by taking its mean depth, or the mean radius of its surface, this level may be supposed variable by reason of any local convulsive movements of the dry land or bed of the sea, any change of dimensions of the whole globe, or any alteration of the mean temperature of the water. First of temperature. If we take the mean temperature of the ocean at the equator 81·5 F., its temperature at the poles 0·0 F. on the surface, and at some depth (d) 81·5 F.; and suppose, in conformity with some hypotheses from organic remains, that the whole surface of the globe was formerly subject to a temperature equal to that of the equator; the ocean at that period must have been defined by a longer radius.

Variable with Change of Temperature.—The expansion of the polar waters, supposing them to have been fresh, would be at the surface only to the extent of 4°·0, because at temperature 0°·0 F. fresh water occupies nearly the same space as at 77°·5; at nearly half the depth (d) it would expand through 42°·75, at the depth (d) nothing. Average expansion $= 22°·4$, which corresponds to $\frac{1}{184}$ of the depth.*

* Fresh water expands about $\frac{1}{22}$ for 180°.

If we suppose d to be 10,000 feet, the polar expansion = 54 feet. But if we suppose the water to have been salt, the expansion at the polar surface, from 0°·0 F. to 81·5 F.

$$=\frac{81{\cdot}5}{180}\times\frac{1}{20}=\frac{81{\cdot}5}{3600}=\frac{1}{44}\text{th}^*$$

of the depth and at other latitudes

$=\frac{1}{44}\times$ sine lat. At the depth (d) nothing. The average expansion would therefore be $\frac{10000}{88}=114$ feet $=228$ feet.

It is evident that such fluctuations of level, however real, are not adequate to explain the desiccation of large tracts of land.

What might be the effect of a general change of dimensions of the globe, through variation of its own temperature, is beyond our power of investigation, because we do not know in what ratio the solid and liquid parts of the globe would alter their dimensions.†

We may, however, consider the effect of a general change of dimension of the nucleus of the globe, supposing the superficial temperature unaltered. According to all analogy of organic forms, the globe may be supposed to have grown cooler continually, and thus to have contracted in bulk; but this, by shortening the mean radius, would cause the ocean level to *rise* upon the land, which is contrary to the effect we wish to explain. If we even allow, for the sake of argument, an augmenting diameter to the globe, this must go to a very great amount before the level of the ocean, as compared to the land, would be sensibly affected. If the ocean be 5 miles deep, the diameter of the earth must be augmented 1½ mile to cause the level of the water to sink relatively 10 feet, and to sink it half a mile the radius of the ocean must augment 400 miles. It is unnecessary to prosecute this inquiry, for a sinking of half a mile would be insufficient for the desiccation of the whole dry land, even allowing the great mountains to have been uplifted.

Variable through Intestine Movements.—The most interesting part of the inquiry remains to be more carefully examined—the variability of the ocean level in consequence of displacements of the solid land. We shall put the case in three forms, and according to each of these imagine the present continents to be depressed beneath the waters of the ocean, as they once certainly were.

First. We may suppose no vacuum to exist below the crust of the earth, nor any receptacle occupied by air or gases into which the

* Salt water expands about $\frac{1}{20}$ for 180°.

† Since this section was written, Mr. Babbage has made known some interesting views bearing on this subject (Proceedings of the Geol. Soc., 1834), and Mr. Hopkins has attacked the problem of the earth's internal fluidity.

solid land could sink, but that a sinking in one place should be compensated by a rising in another, so that the cubic dimensions of the globe should remain unchanged. Moreover, to put the case to extreme, it may be a condition that the land shall sink so that water shall cover the whole surface. In this case the level of the ocean would rise, that is, the mean radius of its curved surface would be lengthened, by a quantity depending on the mass of the solid land submersed, and on the relative area of land and water. This relation of area is more than 3 water to 1 land. The cubic content of the solid land may be thus estimated. In England, Wales, and Scotland, the average height of those conspicuous mountain masses which appear to give shape to the whole country is about 3,000 feet; and if we consider this as the apex of a cone whose base is the whole area, we shall have the mean height of the land above the sea $= \frac{3000}{3}$ feet. The mountain masses, however, do not really affect, by their special elevation, more than a fraction of the area of the British Isles; the far greater part of the land depends on heights not exceeding 1,000 feet. If the mountain tracts be called $\frac{1}{2}$ of the area, and the hilly and more depressed parts $\frac{1}{2}$, we shall find the mean height of the whole mass of land $\left(\frac{3000 + 1000}{3 \times 2}\right) = 666$ feet. But on acconnt of the valleys which divide the principal masses, we may reduce this—say to 500 feet.

This principle applied to the continents of Asia and America would give in round numbers about 2,000 feet mean altitude of land; and as the area of the expanded ocean would be four times as great as the land is now, the total mean elevation of the water, by the submersion of the whole mass of land, would be about 500 feet; a quantity too small to be of use in explaining any but the lesser order of geological phenomena, and which may be considered as the extreme limit of oceanic rise.

Secondly. We may suppose the existence of cavities into which the solid land might sink, so that there may be no elevation in another place corresponding to the given depression. To put this also to extreme, we may imagine the very improbable case that a mass of solid materials equal in bulk to all the solid land above the water, should sink into a cavity, and that the surface of the submerged land should be level. The level of the ocean would be nearly unaltered, except in a small degree, by reason of its shallow expansion over the area of the land. We might go on to suppose even the enormously improbable case of cavities existing so large as to admit twice the whole solid mass of the continents, and that these should

sink with an equal bulk of materials into these cavities. Even in this case the ocean level would only be lowered 500 feet.

Thirdly. If we suppose contemporaneous or successive elevations and depressions, however extensive, the ocean level would oscillate about a constant line.

Conclusion Adopted.—It is evident, therefore, that by no stretch of conjecture, that is not absolutely monstrous, can we torture the known laws of terrestrial arrangements into agreement with the hypothesis of any but small changes of the level of the ocean; a conclusion of the highest value, since it enables us to argue upon that level as a general standard to which we may refer all the effects of internal movements, in whatever period, and by whatever forces produced. It must be remarked, however, that it fixes no limits to the effects of the temporary violence induced in the ocean by such movements, because these effects would be proportioned to the impulse with which they were attended.

Gradual Elevation of Land.—It appears that we cannot in all cases understand the possibility of the elevation of land *out of the sea* by the mere effect of local convulsive movements, but must in addition admit the gradual rise of large tracts of land whether convulsed or not at some earlier epoch. England is an unexceptionable example; and probably every country will be found to require the same admission. The necessity for admitting this gradual elevation of the whole country, is first suggested by the difficulty of otherwise accounting for the altitude of the tertiary and other marine strata, which have been deposited long since the great convulsions which partially or completely raised the primary and other old systems of rocks, and are, in general, remarkably free from the traces of any such events. The older geologists relieved themselves from this dilemma, by inventing the gradual diminution of the level of the ocean; the moderns meet the difficulty by supposing a gradual intumescence of the land. The former mode has been proved to be incredible, the latter we certainly do not yet understand, but it is not at variance with the established facts of convulsive elevation.

Where convulsive movements can be traced in their effects we have a good local cause for the local elevation of the ancient bed of the sea; but where no such movements can be traced, and yet the land is raised far above the sea, it is clear that we must neither admit convulsion, nor deny the relative change of level of land and water. Now the areas of country which are elevated, but not convulsed, in such a way as to account for this elevation, are very extensive. The greatest portion of the level regions of the globe is thus circumstanced. In many instances we might plausibly explain the facts by supposing that the same localities (as mountain chains and groups) which had been in very ancient periods liable to great convulsive movement,

were during later periods influenced by more gradual and continual subterranean expansion, so as to bear up on their slopes the newer strata formed and in process of formation. This would apply to England, whose great centres of old convulsions are nearly confined to the western borders, and it seems equally suitable to most countries whose lines of mountains correspond with the general figure. The principle, once admitted however, will be found applicable to all situations, and equal to solve a very difficult class of problems in geology. It may even clear our way through the cases of alternate elevation and depression, such as the temple of Serapis on the Neapolitan shore: for whatever be the cause of local intumescence, it may be discontinuous or intermittent, and elevation in one quarter may be counterbalanced by depression in another.

Proposal of a Hypothesis on the Subject.—But is such an assumption of local subterranean expansion consistent with what is known of the interior constitution of the globe, or is it a vain speculation? So little is known of the interior of the globe, that almost any hypothesis is safe from coming into collision with that knowledge, provided it allows of given mean density, and a specific gravity increasing toward the centre. Newton supposed the spheroid to be homogeneous; it has been found that this supposition is by no means fitted to fulfil the observed conditions of the problem of the earth's figure; and the irregularities of attraction indicated by the pendulum experiments, and of curvature by direct meridional measures, seem to show that the *concentric masses* of the spheroid are *not* of *uniform* density.

This being allowed, there would seem no objection to suppose that the densities along any one *radius* of the spheroid are *variable*, by reason of intestine movements among the unequally dense parts of the concentric masses, and this would exactly answer the conditions of the geological problem. For the length of any radius of the heterogeneous spheroid would necessarily vary with the densities; and considering the small proportion of the height of the land above the mean radius of the latitude, it is clear that small internal changes in a length of 4,000 miles would easily account for variations on that line to the extent of 1,000 feet or yards.

This *hypothesis* would give a gradual and prolonged elevation in some parts and corresponding depressions in others; it would not affect in a sensible degree the astronomical elements of the planet, but would change more or less completely its hydrographical boundaries. It appears consistent with the inference to which we were conducted while studying the phenomena of mineral veins (p. 552), *viz.* that under the same region of stratified rocks different sorts of igneous rocks had been at different times developed, and is suggested again by the successive consolidation of trisilicated and silicated

minerals, (p. 500); and at all events may be used as a first contribution towards a sound mathematical theory of general subterranean movements independent of volcanic convulsions.

How Possible.—To reconcile this view of the variation of density under given tracts of the earth's surface, with the inferences which have been already presented concerning the interior constitution of the earth, is not difficult. We have only to remember that, in the course of the consolidation of the crust, the silica and trisilicates of granite, &c., first solidified, have a specific gravity of about 2·6, while the silicates, remaining liquid at the same temperature, have a specific gravity of about 3·2 and more. Now let the solidification of the first group have proceeded so far under a given country, as to form, partly by cooling, and partly by pressure, those partitions which enclose the liquid bases of volcanoes. If this solidification proceeded only to the depth of thirty-two miles, we should have the specific gravity on the lines or over the areas of this crystallization diminished, and that of the liquid parts augmented, so that the solid part ought, as compared with the average, to have a tendency to rise, and the liquid part sink, until the columns had the relative height of 26 and 32 miles. This is to take the extreme case; but diminish the calculated difference as we please, it is obviously a true and effective process of nature, capable of giving long periods of elevation to some tracts and of depression to others, and of calling up very powerful internal pressures without convulsion.

Again, if over the parts remaining liquid, gaseous pressure should be generated by any of the processes already suggested, the depression of the area might be arrested, and even reversed; and the release of this pressure might again cause a return of the depression. Other variations may be easily imagined, and upon the whole this hypothesis, which was proposed in the former edition of this treatise, appears to us to have only gained strength and generality, in consequence of subsequent discoveries.

Relations of Land and Water.—We may now attempt a brief sketch of the relations of land and water in particular regions, during the successive geological periods, and notice the character of the agencies concerned in producing them.

It is sufficiently evident that we are precluded from any attempt to assign these relations generally, because we cannot know what tracts of land were once raised above the sea, and have since been submersed. This applies with great force to the periods, whatever they were, which preceded the formation of what we call palæozoic strata; for concerning the question of the existence of land during those periods we cannot even offer a conjecture, except upon the basis of inquiries into the remains of terrestrial organic forms embedded in these strata. The evidence which they afford negatives,

as far as it goes, the existence of land plants; but it is chiefly by the great extent and uniformity of character of these deposits, and by the absence from them in the lower parts of marks of littoral or fluviatile action, that geologists might justify a belief that little or no dry land divided the wide primeval ocean. We pass to consider the state of things during the palæozoic period.

During the Palæozoic Period.—It is admitted that the greatest effects of the elementary movements which can be traced in the existing ranges of mountains were posterior to the lower palæozoic deposits; but there are good grounds for believing that dry land in some (unknown) situations began to furnish vegetable reliquiæ, during, at least, the later part of the period occupied in the deposition of the silurian system. *First*, there is the certainty that some disturbing effects of igneous agency are traceable among very old members of this vast group of rocks. *Secondly*, the existence of carbonaceous matter (anthracite) among them. *Thirdly*, in the uppermost part of the series occur land plants.

At the Commencement of the Carboniferous Epoch.—It is highly interesting to observe the harmony of two classes of results bearing on the relation of land and water at this epoch. Some of the most extensive and important physical features on the western side of the basin of Europe have resulted from convulsions *preceding* this epoch, which certainly raised out of the sea many remarkable ranges of high ground; and the most considerable accumulations of land plants which have furnished the substance of coal in Europe and North America, *followed after an interval* those convulsions. It may, perhaps, eventually be possible to derive, from the comparison of the local centres of elevation with the limited fields of coal, some conclusions as to the physical geography and other circumstances of the place of growth of the vegetables; at present we shall only venture three remarks. 1. The deposit of coal plants does not in general follow immediately, but after some interval, the uplifting of certain tracts of land; for between the uplifted primaries and the phytiferous secondaries, great thicknesses of conglomerates holding few or no plants, and beds of limestone full of marine shells intervene. 2. The plants which most predominate in the older parts of the carboniferous deposits in Great Britain (coniferæ) appear like the vegetation of a mountain district in a warm climate, while those which abound in the younger deposits of the same period (cactiaceæ, equisetaceæ, &c.) may be more successfully compared to plants of plains and marshes. 3. The coal basins appear related in position to the ranges of primaries uplifted before the deposition of coal, and not to those of subsequent ages. This is an important fact, and must be further developed. On geological maps of the British Isles, the local relation of the lower palæozoic and carboniferous strata may

be seen, and the latter will be observed to form a broad belt parallel to the general course, entering into the indentations, and surrounding the insulated eminences of the former. But along the ranges of the Alps and Pyrenees, no such bands of carboniferous rocks occur. The British primaries were uplifted *before* the carboniferous period, the great European ranges *after*. Coal is, however, not uniformly spread over all the area of the carboniferous rocks. It occurs in the great valleys of the Forth and Clyde, *between* the Grampian and Lammermuir ranges, *in* valleys of the Lammermuir; (Sanquhar;) *round* the Cumbrian mountains; *round* the Welsh mountains; *in* hollows of the Anglesea primaries. Besides these remarkable juxtapositions, the long range of the great northern coal fields is still partially united with the coal deposits encircling the Cumbrian and Welsh mountains; and it is only by the effect of immense subsequent convulsions, and the consequent unconformity of the triassic formation, that it does not appear completely united with them.

The immense coal deposits of Ireland are in the same way surrounded by primary strata, which were raised above the sea before the accumulation of the coal. Parallel to the Hundsrück and to the Taunus and Ardennes, which were elevated about the same early period, lie the coal deposits of Saarbruck, the Netherlands, and Westphalia. Comparing this statement with the inferences concerning the growth of the plants of the carboniferous period, and with the peculiarities of the several coal fields, we seem to find a fair basis for reasoning concerning the original habits of fossil plants, which may eventually lead to important results.

Before the Saliferous Epoch.—The elevatory movements consequent upon the deposition of coal appear to have been very general and extensive, and in the basin of Europe to have materially contracted and altered the boundaries of the sea. In England especially this effect is clearly shown by the rising above the sea of the large tract reaching from the Tweed to the Trent, and including nearly the whole of the space between Berwick, Carlisle, Liverpool, and Nottingham; thus forming a large and nearly united tract from the Pentland Frith to Cheshire. To the same periods we must refer a large augmentation of the previously elevated regions of Wales. It will thus appear that nearly all the northern and western parts of the island of Great Britain were then raised above the sea, which still flowed over the sites of all the midland, eastern, and southern counties. The greater part of Ireland had also emerged. Besides these greater elevations some smaller tracts, which now appear as detached groups of mountains, were then conspicuous as islands. Charnwood forest, the Dudley district, and Mendip are examples. The Cumbrian mountains were half surrounded by a sinuous arm of the sea, which washed the feet of the Pennine chain from Kirkby

Stephen to Brampton, expanded into the southern counties of Scotland, and perhaps connected itself along what is now a part of the Irish Sea, with a great diversified gulf in Cheshire, Warwickshire, Leicestershire. To the east of a line drawn from Newcastle through Nottingham to Exeter, we may suppose it to have been all an open sea as far as the Ardennes and the Harz. It thus appears that some of the marking features of British and European physical geography are of very high antiquity; and however modified in detail, by subsequent internal movements and superficial wasting, their larger proportions and general effect in those early periods may be very well judged of from the characters which they retain at present.

It might appear that, during the saliferous period, the elevated lands nourished no great profusion of vegetables; for throughout the whole of Great Britain the magnesian limestone and new red sandstone system is wholly, or very nearly so, devoid of such remains; and though in a few places in Germany plants are found in some parts of this system, they rather confirm than oppose the general inference.

It does not seem possible to trace any close dependence of the local character of the saliferous system upon the circumstances of the physical geography of the regions; for, correctly speaking, there is very little of *local* character, except what is imparted by the unequal extension of the limestone groups; and these are probably wholly derived from marine decompositions. Along the Vosges mountains, perhaps, a peculiar sandstone conglomerate may have been derived from these mountains.

Scarcely anything in geology is more remarkable than the great uniformity of appearance of such extensive deposits as those of the saliferous system, with such few remains either of marine or of terrestrial reliquiæ. The prevalent red colour of this system is of itself a circumstance of great interest, though of unknown origin. In many cases this colour is derived from a superficial coating of oxide of iron round the internally clear quartz grains; and there can be no doubt that chemical agencies were then in operation of a very extensive and very remarkable kind. It is difficult to avoid believing that the life of the marine mollusca and radiaria was much controlled by these agencies.

Before the Oolitic Epoch.—The deposits between the coal system and the tertiaries succeed one another so regularly in England, and even throughout Europe, that to explain the successive parallel outcrops of the several strata an obvious supposition is a gradual elevation of the pre-existing land, or a gradual retreat of the ocean. This problem becomes, however, still more intricate when we add the following general truths:—1. That in England the oolitic strata, which succeed the red marls, form hills of greater height than *any*

one point of the saliferous formation. The same is true for Germany and France. 2. That there exist beyond the general range of the oolitic outcrops many far detached hills of these strata resting on and overlooking broad plains of red marl, which seem to be in an undisturbed position. It is obvious in these instances that the surface has been subjected to enormous waste by the violence of watery currents. In every theory of diluvial or alluvial action it is supposed that these denudations were performed upon the previously dried and elevated land; but few speculators have had the boldness to attempt the solution of the difficulty, by assuming that the *inversion of relative level* between the red sandstone and the oolitic systems is wholly due to the wasting action of water.

Perhaps we shall best consult the true interests of the science by not insisting much upon any mode of accounting for these yet insufficiently examined questions; but it seems right to observe, that gradual elevation on the west and depression on the east of the south-eastern parts of England, parallel to the line of the oolites, and prolonged in duration through the whole period of the saliferous, oolitic, cretaceous, and tertiary rocks, would fully agree with the general physical features of the surface of the district, the minuter inequalities of which may certainly be ascribed to superficial watery action. This view appears to agree well with the general character of the upper saliferous, oolitic, and cretaceous deposits, which exhibit many repetitions of analogous rocks and fossils, many deposits of limestone and clay, such as might be formed in quiet or deep waters, with but few beds of sandstone. From some of these local sandstones we learn the fact, that some parts of the land which bordered the oolitiferous sea, nourished a variety of plants, characterized upon the whole by a predominance of vascular cryptogamia and coniferous phanerogamia, different from those of the older coal tracts.

Effects of Convulsions on the Deposition of Strata and on Organic Life.

The formation of extensive conglomerates has been already shown to be a natural consequence of convulsive movements; and it is in some cases very probable that the disturbance was centered in the immediate vicinity of these accumulations. But it would be a gratuitous contraction of a very interesting field of research to limit our inquiries into the effects produced by subterranean movements on the deposition of strata, if we did not take into consideration the peculiarities of mineral character belonging to the several systems of marine deposits, the alternations of marine and fresh water rocks, and the succession of races of organic beings. What dependence

there may be between these phenomena on the one hand, and subterranean movements on the other, will undoubtedly be revealed by the progress of inductive geology, and results of a very interesting kind will flow from such a discovery. At present, we can only sketch a dim outline of a subject as yet scarcely emerging from obscurity.

Mineral Characters of the Systems of Strata.

Actual Process of Nature.—Sedimentary deposits, whether they are occasioned by the action of streams and floods from the land, or of tides and currents in the ocean, have a mineral character depending on the nature of the materials acted upon. The same great stream may, according as its different feeders predominate in their action, deposit materials of different quality; there may be in such deposits effects depending on the season of the year, but all such differences are periodical, and a series of alternations of given mineral aggregates is the result.

The action of the tides in a certain direction, is also liable to periodical variations of intensity; the coasts worn by tides may be unequally affected at different times, and the accessions of materials from the land may be irregular; still these minute inequalities are almost wholly lost when we contemplate the average results of a long-continued course of the same tidal action.

Deep-sea currents, so long as they follow the same channels, can hardly be supposed to produce any but very uniform admixtures of sedimentary ingredients.

When, therefore, we find a series of sedimentary strata to consist of repetitions of the same materials, or of recurring alternations of different materials, the whole is reasonably referred to a series of the same, or similarly alternating effects of watery action upon the same tract of land, the same line of coasts, or the same channels of the sea.

On the contrary, the suppression of one class of deposits, and the production of another, clearly marks out to us that the water has ceased its action on the land, coast, or ocean bed, which it formerly wasted, and transferred its attacks to a new quarter.

It was not the perception of these simple laws of modern nature but a clear recognition of their effects in older periods, that led geologists to agree in classing together portions of the innumerable layers or strata into certain groups or formations, according as they are identical or analogous in their nature, very gradually change from one to another, or consist of a series of recurring mineral terms; and in dividing these groups at the points where new terms appear and old ones are suppressed. Thus the suppression of red

marl, and the introduction of blue clays, marks the boundary of the saliferous and oolitic formations; the suppression of oolite, and the introduction of green sands, marks the limit of the oolitic and cretaceous formations.

No Universal Strata.—Whatever view we adopt of the origin of sedimentary rocks, there can be no doubt that, even from the earliest geological period, the bed of the sea must have been composed in different regions of different materials; this must have been the case, even if we carry back our thoughts to that remote epoch where we may suppose that nothing solid existed at the surface of the globe, except the products of heat; for these, in fact, contain nearly all the varieties of minerals, and nearly all the elements of the composition of stratified rocks. The very earliest formations which we have yet succeeded in tracing, exhibit themselves in two very distinguishable masses; the gneiss and mica schist system on the one hand, and the clay slate system on the other. When, by the partial elevation of these rocks above the level of the sea, the ocean was divided into separate parts, local differences of the sedimentary, and even chemical deposits, must speedily have resulted; and as the extent of land increased in any particular region of the globe, the deposits in the residuary seas thereabout must necessarily have become more and more dissociated from those of other regions.

It is, therefore, very evident that there can be no universal strata; that during the greater part of the geological periods, rocks of very different nature may, and, indeed, must have been contemporaneously deposited; although, according to the circumstance of the cases, the peculiar products of one region may have been, by oceanic currents or other causes, mixed with those of another, and so a continual or interrupted analogy between the series of strata in each maintained.

Changing Sediments Connected with Subterranean Movements.—We have now arrived at the point when the co-ordination of the diversity of sedimentary aggregates in a given oceanic basin with subterranean movements, and the dependence of the former on the latter, may be presented in the form of a very probable inference. Geologists have long been accustomed, while reasoning on the phenomena of tertiary rocks, to recognize the principle of the dependence of the local difference between contemporaneous strata in different basins upon the physical structure of the region from which the materials of these strata were derived. It has been already shown that the successive diversity of strata in the same basin can only be understood by admitting that the different sediments were brought from different regions; it is evident that for this end the drainage of the land, the flow of the tide, or the direction of oceanic currents,

must have been changed; this can only be ascribed to an alteration in the local relations of land and water, that is to say, to subterranean movements.

When this change of the sedimentary deposits is sudden and complete, we may generally feel assured that it is owing to violent subterranean movements, which have opened a new communication with the basin: the exact *site* of the centre of convulsion may perhaps not be ascertainable, though in some particular instances the *direction* of the new currents may be inferred, and thence their local origin conjectured. When the changes of sediment are gradual or alternate, we must apply corresponding inferences with greater caution.

In some cases slight movements might accomplish great changes in the nature of the deposits. The map of the terraqueous globe shows us how easily, at particular places, the waters of different oceanic *alvei* might be brought into union by the lowering of an isthmus or the opening of a strait. If the Mediterranean were connected through the Red Sea with the Indian Ocean, would not the deposits in each of them be reciprocally influenced? Such internal movements as might occasion this appear trifling, when compared to the disturbances which we know to have been many times effected within the range of geological chronology.

Successive Races of Marine Animals.

Local Change of Organic Races.—If, in consequence of internal movements, a given basin were opened to the reception of currents and sediment from a new quarter of the ocean, it could scarcely happen otherwise than that a change should arise in the inhabitants of that basin, by the extinction of some and the introduction of other species. Scarcely excepting even the earliest series of fossiliferous deposits, there is nothing in geology to indicate that the distribution of species over the globe was regulated by different laws from those which now prevail. The superficial temperature of the globe was perhaps more equable; and for this reason organic forms might be more extensively distributed; there might be *less* local distinction than at present; but yet each species had its definite boundaries, and different regions were characterized by peculiar races.

Upon the establishment of a communication from one such region to another, there must necessarily be a *transference* of organic life, at least in one direction, according to the locomotive habits of the creatures, and the influence of currents upon them and their ova, and other circumstances.

It was with this in view that the passage (p. 71), relating to

the succession of races, corresponding to successive deposits, on a given part of the ocean beds, was written.

How remarkable is the coincidence of great convulsions, decided changes of mineral aggregations, and substitution of new organic remains, needs only to be mentioned; for these three orders of effects are all combined in modern geology to characterize the groups or systems of stratified rocks.

Fresh Water and Marine Alternations.

Few geological phenomena declare more plainly their dependence upon ancient convulsions than the alternations in a given basin of strata, of fresh water and marine deposits. Not that in every case where we see fluviatile or even lacustrine shells alternating with marine exuviæ, we must suppose the levels of land and sea to have been changed, because at the mouths of some rivers this might happen from the bursting of a lake, a violent inundation, or even the natural course of things; but when, as in the coal field of Yorkshire, over the marine deposits lies a great mass of matter derived from the land, and in this a particular layer of marine exuviæ; when, as in the Weald of Sussex, we observe above the marine deposits of the oolites a great thickness of fluviatile deposits covered by marine green sands; or, as in the Isle of Wight and the basin of Paris, see really lacustrine marls and limestones interposed among really marine strata; the conclusion seems inevitable that these are effects of changes in the relative level of land and sea. It would, however, be too much to assert in every case that the internal movements *were centred* near the places where we witness some of the effects. On the contrary, we may perhaps probably often be merely looking upon the consequences of convulsions which happened at great distances of space, and which produced near their centres of action wholly different phenomena. This mode of interpretation applies very well to those instances in which repeated alternations of marine and fresh water productions occur without any indications of corresponding local disturbances. As an example, we may cite the marino-lacustrine formations of the Isle of Wight.

The Weald of Sussex.

Application to a Case proposed by Lyell.—One very obvious effect of convulsive movements, whether sudden or gradual, must always be a more rapid rate of waste, both in the land and along the coasts, than usual. It will, no doubt, be possible hereafter to draw from the *varying rate* of sedimentary aggregation in a given basin some important evidence concerning the amount and duration of the in-

ternal movements which caused a more than ordinary accumulation of materials in the sea.

By combining with this the results of an inquiry into the local site of the convulsion, as inferred from the direction of *new sediments*, we may eventually be able to point out, with more or less probability, the original sites of these materials, and thus show how in ancient periods the wasting of one given tract of elevated rocks has contributed materials for the accumulation of new deposits in the sea.

So long as, in the prosecution of this research, we confine ourselves to the methods of the inductive philosophy, our progress will be real, though slow. New circumstances will arise to quicken the process and solidify the results, and light will gradually break in upon the yet obscure problem of the physical geography of early geological periods.

Lyell's persevering investigations into the history of the tertiary strata have produced a very remarkable attempt to determine the local origin of the materials of the English tertiaries, and the local seat of the corresponding subterranean disturbances.

The geographical relation of the anticlinal axis of Sussex and Hampshire to the tertiary deposits on either slope, has long fixed the attention of geologists. It was proved by Dr. Buckland, that the tertiary basins of Hampshire and London were once, at least, partially connected. It was known that the first deposits above the chalk were such as to indicate prolonged action of agitated waters, that the subterranean surface of the chalk was uneven, and that among the tertiary deposits were abundance of pebbles apparently derived from water-rolled chalk flints.

Lyell supposes that "the chalk of the south-east of England, together with many subjacent rocks, may have remained undisturbed till after the commencement of the tertiary period. When at length the chalk was upheaved and exposed to the action of the waves and currents, it was rent and shattered, so that the subjacent secondary strata were exposed at the same time to denudation. The waste of these rocks, composed chiefly of sandstone and clay, supplied materials for the tertiary sands and clays, while the chalk was the source of the flinty shingle and of the calcareous matter which we find intermixed with the London clay. The tracts now separating the basins of London and Hampshire were those which were first elevated, and which contributed by their gradual decay to the production of the newer strata. These last were accumulated in deep submarine hollows, formed probably by the subsidence of certain parts of the chalk, which sank while the adjoining tracts were rising." *

* Principles of Geology, vol. iii., 1st edition.

Without following the range of ingenious arguments employed in fortifying his hypothesis, we shall notice the facts which seem most clear in their evidence, and which can be interpreted without theoretical assumptions.

Circumstances Favourable to Lyell's View.—1. It is certain that the Wealden country, with some other tracts in the south of England, has been uplifted by subterranean movements, independent of that general rise of the whole of the eastern part of the island before adverted to (p. 584). Whether this was accomplished by one or many successive movements cannot be decided by direct evidence; it would appear, however, that the convulsion was not ended till after the deposition of the whole eocene tertiary series.

2. It is undoubted that the upper secondary strata disclosed in the Weald once extended much farther towards the central axis, and have been exposed to enormous waste and denudation. There is nothing to negative the opinion adopted by many geologists, that the whole of the area enclosed between the north and south Downs was once completely covered over by the chalk and the subjacent green sand system; but this admission is not really necessary to the hypothesis.

3. The tertiary basins on the northern and southern sides of the axis of elevation of the Weald, contain nearly the same kinds of sedimentary deposits in the same order of succession, so that both of them must certainly have been influenced by the mechanical agency of water, flowing under nearly the same conditions, from the same physical region, or from regions consisting of the same materials equally exposed to aqueous erosion.

4. The materials of the tertiary strata, in the basins of London and Hampshire, are analogous to those which have been removed by denudation of the Weald; since they consist of various coloured sands, which may be imagined to be derived from the green sands and Hastings sands, and of clays which may be supposed to have been furnished by the Gault and Weald clays, and contain pebbles which are allowed to be rolled chalk flints.

If we could venture to add to these statements, that the *order of succession* among the strata of the tertiary series was exactly that of the successive emergence of the chalk, green sands, Weald clays, and Hastings sands, the hypothesis would stand on much firmer basis than is afforded by the above favourable circumstances. After an impartial consideration of the case, we have not been able to trace such a clear dependence of the successive members of the tertiary series upon the nature of the secondary strata successively wasted, as is implied in the hypothesis, that the gradual wasting of the Weald has furnished the materials for the gradual filling up of the basins of London and Hampshire.

Chalk, the secondary stratum liable to be *first* wasted, and consequently to yield the materials of the lowest tertiaries, has furnished only a mass of flints interspersed among the variegated sands and clays, (with very little calcareous matter,) such as might claim origin from those strata of the Weald which were the *last* to undergo the influence of littoral agitation. The lower group of the Weald should have left a predominant mass of sands above the other deposits in the tertiary basins.

It may be replied, in favour of the hypothesis, that the fine particles of chalk might remain suspended, or be entirely dissolved in the water, until the period of the formation of the London clay, which is partly calcareous; that the coloured sands associated with flint pebbles were derived from the green and iron sand groups; and that the uppermost deposit of the tertiary groups may have consisted of sand which has since been removed.

Principal Objection to it.—Perhaps the most formidable of this class of objections is the *total and absolute* deficiency of any of the organic remains of the Wealden rocks (except in rolled chalk flints) in any of the tertiary deposits in question. This applies especially to the tumultuous deposits of sand and shells which lie above the chalk; for here surely some of the numerous organic fossils of the green sand system, or some few fragments of the rocks, of the Hastings sands, with plants, shells, or bones, should have been found.

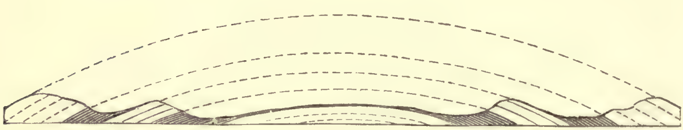
Some recognizable specimens of the shelly marbles of the Weald clay ought, in some one locality or other, to have been discovered in the argillaceous beds which form a predominant feature in the tertiary basins. If it be remembered that we are here speaking of very contiguous districts, that the distance which the materials can be supposed to have been removed is only a small number of miles, and that it is matter of common observation, that by some currents or other, whether diluvial or alluvial, of transient or prolonged duration, vast quantities of organic remains, separate, or embedded in recognizable masses of sandstone, limestone, shale, and ironstone, have been drifted fifty or one hundred miles; it must be allowed that the total absence, from the tertiary strata, in all situations yet examined, of any fragments of the Wealden rocks or fossils, is a very serious difficulty to the reception of an hypothesis which derives the one from the other.

Hopkins on the Weald.

Mr. Hopkins has made a successful application of his theory of elevation of the strata, by the expansion of limited areas, to the phenomena of the Weald and the Bas Boulonnais, which is con-

nected with it geologically. In this large elliptically elevated area, 150 miles long from east to west, and 40 miles broad from north to south, (within the chalk escarpment,) Mr. Hopkins recognizes, besides the general broad anticlinal slopes, which determine the main features of the district, several lines of flexure, and fracture, and anticlinal axes; and he also defines some of those transverse lines of movement, depending on the main axis and boundaries of the district, which are directly deducible from his theory. He combines with the elliptical elevation of the Weald, the more elongated system of parallel movements of the Isles of Wight and Purbeck. The remarkable breaks in the bounding chalk ranges which give passage to the rivers flowing from the Wealden northward and southward, are shown to correspond in situation with cross fractures, indicated by theory, and sometimes rendered probable, and occasionally proved, by observation. One considerable decisive and simultaneous movement is appealed to for the dislocations of the elevated mass, and for the production of its main physical features, but there is still a necessity of admitting a slow and gradual continental elevation to account for the denudation of the district.*

* Geol. Trans., vol. vii.



375. General section of the Wealden, showing the probable extent of denudation.

1 Hastings sand. 2 Weald clay. 3 Lower green sand. 4 Gault. 5 Upper green sand and chalk.

CHAPTER XIX.

PERVADING EFFECTS OF HEAT.

The investigations which have now been traced, lead to a general view of the earth's interior condition, which may be thus expressed.

I. Whatever may have been its earliest cosmical relations, it appears first in geological history as *a spheroid of revolution*, whose parts have taken their relative place under the joint influence of gravity to the centre and rotation on an axis. The density increases toward the centre, the surfaces of equal density are elliptical to the same axis as the external oblately spheroidal surface.

II. This spheroid cools by radiation into the celestial spaces; and by this consolidation begins at the surface, and brings into existence the variety of molecular aggregates which diversify the exterior crust of our planet.

III. Contraction of the whole mass follows, but unequally in the solid external and liquid internal parts, so that either separation takes place between them, or the crust is pressed into accommodation with the interior. In the latter case, depression of the surface would result. In the former case, it may be admitted that gas, extricated from the solidifying mass, might uphold, at least temporarily, the solid arch of the crust. Thus the earliest inequalities of the surface would be occasioned; and from the beginning a continual system of reciprocal depressions and elevations would be established by that "reaction of the interior of a planet on its surface," which is regarded by Humboldt as the most general aspect of the earth's volcanic force.*

IV. In the earlier periods of the earth's contraction, these phenomena of elevation and depression must be supposed to have been of a general† character, at first absolutely, and afterwards comparatively free from local inequalities of consolidation. The consequence would be, that the surface of the spheroid would be wrinkled by folds of elevation and depression, growing more and more deep, and with the progress of time more and more complicated. In remarkable harmony with this view, is the well-known fact of the amazing frequency of anticlinal and synclinal and more complicated flexures of the palæozoic strata—in all parts of the world—flexures often completed before the close of that period.

V. In later periods of the earth's contraction, local inequalities of

* Humboldt, in his great work "Kosmos."

† It is necessary to warn the reader that, in this treatise, the word *general* has the meaning given to it in exact *science*. It comprehends the whole area, and all the special cases, of the problem in hand; not merely the greater proportion of them, for which such words as *usual*, *frequent*, *common*, are suitable.

consolidation—partly dependent on the earlier flexures, partly produced by the inequality of molecular aggregation (as, for example, by the separation of different orders of silicates)—must have overcome the generality of the phenomenon of reciprocal depression and elevation, and limited them to separate areas or districts, in which one or the other of their opposite effects might take place—and in which one might follow the other—so that the same tract might be alternately raised and depressed.

VI. In nearly all cases the depression must be supposed to be real and gradual,—that is to say, part of the earth's surface affected by it must be gradually carried nearer to the centre than it was before; the elevation may have been in many cases only relative and gradual, but in others real and unequal,—that is to say, the area may have been removed farther from the centre than it was before, by a force of local pressure, subject to inequality and cessation, (as gaseous pressure). In some cases of real depression, and in many more of real elevation over *a limited area*, the solid crust must be supposed to have been extended; in the former case under the influence of greater heat, (as being nearer the centre than before,) in the latter case under the contrary condition.

VII. In a case of the real elevation of a given area by the general upward pressure of a liquid the crust would be *extended*, beyond a certain strain it would *break*, the broken parts would slide on one another, *so as to occupy a larger area*, and the result would be *faults*, according to the laws already indicated, pp. 34, 35. On the subsequent withdrawal of the liquid pressure, from whatever cause, the subsiding of the arch, whether broken by faults or not, would occasion lateral pressures and probably outward flexures, especially toward the limits of the elevated district.

VIII. In a case of real depression of a given tract, followed after a long interval by elevation there, the effects would vary according to the area moved and the vertical range of the motion. If the area were so extensive as to include a large arc on the earth's surface, the crust would subside into a *smaller area*, and be wrinkled, or otherwise affected by compression and augmented heat. On the re-elevation of such an area, faults would probably be produced. (This seems to have been the case in regard to many of our coal fields, whose flexures are traversed by later faults.) If the subsiding area were small or narrow, and the downward movement great, the rocks would sink into a larger area, and faults might be expected. On the re-elevation of such a tract much local disturbance and complicated internal movements among the masses of the rocks might probably follow. (This may, perhaps, have happened in the Belgian and Somersetshire coal fields.)

IX. The influence of these conditions may not yet have passed

away. It may still be the case that Scandinavia is rising, as Lyell admits, and the low islands of the Pacific sinking, as Darwin believes; not in either case on account of volcanic excitement, strictly so called, but by reason of internal changes of density and local accumulation of aëriform fluids, both the consequence of slow refrigeration. That the earth is still partially fluid within may be seen in the cone of more than one volcano; that it is partially and to a great depth solid in certain regions and along certain lines, the broad areas and long tracts of ground shaken by earthquakes abundantly prove. As long as this mixed condition of the interior obtains, there can be no doubt of the probability of further slow and small vertical movements in the crust of the globe.

Consolidation and Alteration of Stratified Rocks.

In a preceding section we have seen the effects produced by the plutonic rocks upon the strata which they penetrate; effects which suggest to our minds so vivid an impression of the action of heat, that even in the absence of all other arguments from facts, we could not refuse to allow that those rocks had been local centres of heat. The independent evidence arising from the composition of the rocks satisfactorily confirms this inference, and permits us to apply it in circumstances when the actual proximity of igneous rocks cannot be ascertained. These effects seem to be reducible to several cases, depending on the degree of heat communicated, and the substances operated on.

Effects of Plutonic on Stratified Rocks.—1. The *consolidation* of stratified rocks is exemplified in the induration and contraction of shale, and in the development of new faces or joints in it, which sometimes meet one another rhomboidally, sometimes follow the columnar relations of the adjoining basalt, and sometimes imitate slaty cleavage.

2. The *partial fusion* of some part of the substance of a rock, so as to conglutinate its grains, and solidify and harden the whole mass. Thus sandstone is converted to a granular quartz rock.

3. The complete fusion or vitrification of the rock; thus converting shale into Lydian stone and sandstone into a kind of jasper.

4. The complete fusion and consequent rearrangement of the particles into granular or crystalline forms, as in the instance of common chalk in Ireland, common limestone in Yorkshire, the Isle of Skye, and Carrara.

5. The generation of minerals not before existing in a distinct state in the substances affected. The production of pyrites, asbestus, anthracite, plumbago, garnet, &c. along the contact of igneous and aqueous rocks, is a very characteristic and general effect which

appears to result from the actual transfer of the metallic and other matter through the solid substance of the rock, in virtue of electric attractions which may be considered as imparted by the heat.

If Von Buch's notion of the impregnation of rocks with magnesia in the vicinity of augitic trap rocks should eventually be substantiated, it must be considered as a remarkable example of this electric transfer.

6. The sublimation of some portion of the neighbouring substances. Thus the charring of coal, the desulphuration and the debitumenization of shale, are very directly connected with the heating power of the igneous rock, but it is probable that some peculiar conditions were required for such effects in the submarine depths, where most of these operations were performed.

Relation of Igneous Rocks to Convulsions.—The almost universal coincidence of convulsive dislocation of the strata with eruptions of plutonic rocks, seems enough to prove their common dependence upon one pervading cause of internal movement. In the same manner as the modern earthquake precedes the eruption of lava, so the ancient convulsion preceded the injection of plutonic rocks. Also precisely as in the present day the earthquake shakes countries far removed from volcanic centres, so in more ancient periods many tracts were convulsed but not filled, at least near the surface, with melted rocks. As far as at first appears, the common dependence of the two orders of effects upon one cause, is merely to the amount that the mechanical transference of melted rocks has been effected by the same internal pressure which dislocated the strata; whatever occasioned the pressure, and whatever was the cause of the fluidity of the rocks.

Various mechanical modes may be conceived, by which such pressure may have been occasioned, and various conditions assumed for the production of melted rocks, and these may be wholly distinct from one another; but the *exhibition* of these rocks along the lines of convulsion can only be ascribed to the same mechanical cause which produced the convulsion.

Metamorphism of Rocks.

Structural Metamorphism.—In considering the characters of stratified rocks, we find several circumstances which it is difficult to explain without reference to some powerful action subsequent to the deposition of the strata. The consolidation of these rocks, however commonly it occurs, is a phenomenon worthy of attention. In daily experience, we see some degree of consolidation effected in calcareous deposits by the concretionary or crystalline coherence of the particles. But we scarcely perceive any induration of clay, or congluti-

nation of sandstone, without enormous pressure or the application of heat. By the subsidence of the strata to some thousands of feet or yards, which has unquestionably happened in very many cases, these two favourable influences were brought into action. The lower strata were upon the whole sunk to the greatest depth, and experienced the greatest amount of pressure and heat, and these are on the whole the most consolidated; the clays have become slate, the sands quartzitic.

The jointed structure of rocks, as already observed, (pp. 40, *et. seq.*) may have been much aided by heat. Their structure, in fact, indicates the mutual approach of the particles, a process likely to be aided by pressure and heat; it is not surprising, therefore, to find the joints in great perfection among some of the older strata. Similarly, we find that beautiful structure in slate expressed by the term "cleavage" (p. 43,) most developed in the older strata, but with this peculiarity, it is most perfect in the fine grained argillaceous strata, least manifest in the coarse gritstones or conglomerates which alternate with them. In the British Islands this structure is almost absolutely confined to the palæozoic series; though, parallel to certain dikes, mesozoic strata may show it slightly. It is, however, not merely an effect of time, but due to some peculiarity in the history of those rocks.

If the reader will now cast his eye on the diagram (p. 260), and the explanation which accompanies it, he will perceive that the limestone strata under the coal basin of South Wales, which were deposited nearly at the sea level, were sunk during the latest palæozoic periods about 12,000 feet below the surface. In these, a partial slaty cleavage appears. The old red strata, several thousand feet thick, which were still deeper, and more heated, are more marked by cleavage; and the Silurian and Cambrian, still deeper by thousands of feet, are even more distinguished by that structure. It is chiefly in what were the deeper parts of the basin that this effect occurs, for on the north side of the South Wales coal field, the upper silurian strata and the old red beds are often free from cleavage, and it is there only partially exhibited in the lower silurian.

Farther to the north, as in the district of the Malvern hills, Woolhope, Abberley, Dudley, the silurian rocks and all above them are free from cleavage, unless in a very slight degree, and along some small and limited spaces. Yet these districts are marked by great and violent flexures, and even reversals of the strata, so that *pressure* seems here to have failed entirely in producing cleavage. This is the more curious, because, in the same country, parallel to the once heated greenstone dike of Brockhill, the old red shales have admitted a rude cleavage. In these districts, there is no

reason to admit more than a few thousand feet of depression (5,000 to 8,000 feet).

Still farther north, the Cambrian and lower silurian rocks of Charnwood Forest, and the base of Ingleborough, are full of cleavage, crossing great curvatures of the strata. Those curvatures preceded the formation of old red sandstone. There is absolutely no cleavage in any of the upper or middle palæozoic strata, which in the utmost depression which we can trace, may have been some 5,000 or 6,000 feet deep in Yorkshire, and some 8,000 feet deep in Lancashire, but the Cambrian and silurian rocks in which cleavage occurs must have been twice as deep.

From considerations of this kind, we are led to admit that depth in the earth—that is, the heat and pressure, and molecular action favoured by depth—is one of the main agencies favourable to the generation of slaty cleavage in the strata. *Pressure* is clearly favourable. For the direction of the planes of cleavage is parallel to the great axis of movement in the district (p. 45), and our own researches, enlarged by the investigations of Mr. Sharpe, leave no doubt that the compression of the rocks in the direction at right angles to the cleavage planes is real and considerable.* Mr. Sorby has even succeeded in producing by artificial pressure a representation of cleavage structure in a mass of matter originally quite destitute of it. Combining these ideas, we arrive at the following general view. A *large area* of country subsides parallel to a certain axis of movement, and is transferred to a hotter and a narrower space, hotter, as compared to the surface, narrower as the chord is shorter than the arc. End pressure operates on all the strata; heat more particularly on the argillaceous parts; the plates of mica, scattered through these strata, are by the pressure made to assume positions not all parallel, but tending to parallelism, and thus effectually causing fissility in the stone.†

Cleat.—Though, as before observed, there is no slaty cleavage in the coal strata of the northern counties, or, indeed, in Wales, there is a structure of the same order in the substance of coal, called "cleat," which is quite as regular, and extensive, and due to as general a cause. This consists in a series of parallel fissures, often very fine and numerous, which cut across the strata of coal, in planes nearly vertical to the strata, and in directions seldom deviating much in the large area of a coal field. In the northern coal fields this direction is N.N.W. and S.S.E., or nearly so. It scarcely occurs, except in the coal, is not affected by faults, and is not parallel to axes of movement, varies in character from bed to bed, but seems due to crystalline forces, excited uniformly over large

* Sharpe, in Geol. Proceedings.

† Sorby, in Geol. Proceedings, &c.

tracts of country, during the consolidation of the rocks. This structure is of a very peculiar type in the anthracite of Wales.

Sharpe on Mont Blanc.—In a late survey of the structure of Mont Blanc,* Mr. Sharpe has traced no fewer than nine parallel axes of slaty cleavage, crossing the gneissic, calcareous, and argillaceous strata, which dip in various directions, a phenomenon analogous to what the same geologist observed in the country of the Highlands.†

Molecular Metamorphism.—Under this head we class the conversion of earthy carbonate of lime to crystallized marble, which has been effected naturally by the proximity of igneous rocks in many places—as in Teesdale, by the greenstone or whin sill,—in Raghlin, by the basaltic dikes; and artificially by Sir James Hall, in a heated gun barrel. On a large scale, primary limestone is a great example, proving the pervading influence of high heat through a mass of hypozoic rocks, by which the carbonic acid was retained (p. 260). Similarly the change of loose sand, or argillaceous sandstone, to solid sandstone or quartzite, or jasper (p. 518) is a case of the cementation of the grains through heat, and so is the consolidation of clay slate, in which the particles are not merely pressed together, but more or less confluent at the edges. The changes here alluded to are quite complete for large tracts of country in the hypozoic strata—a proof of the pervading or general character of this communicated heat, such as would be the case if these strata were deeply sunk toward the source of heat, as we knew them to have been. They are gradually assumed near trap dikes, and prevail for only a short distance, a proof that the dike was injected by pressure, among strata less heated, that is, less deeply sunk toward the general source of heat.

Chemical Metamorphism.—The last and most extreme change induced by heat, and the chemical and electrical actions which heat sets up, is a real alteration in the nature of a rock. Such a case may be typified by the generation of garnet, in the vicinity of trap dikes and large igneous masses, or in the artificial combinations of the furnace. Near the dike of Plasnewydd, in Anglesea, Professor Henslow collected in the altered and jasperized shales, gray garnets; in the rock of the mountain called the Gable, near the granites of Wast water, are multitudes of beautiful red garnets; and we are thus led by easy analogy to view the innumerable garnets in the mica slate of the Highlands, as really generated in those hypozoic strata, by the same influence of heat as that by which the limestone which lies in them has become crystalline, and by which they have resumed their granitoid aspect.

General Basis of Argument.—Upon the whole we may safely ad-

* Geol. Proceedings, 1855.

† Phil. Trans., 1855.

mit, that igneous rocks have been in a state of fusion beneath the strata, either simultaneously or successively, in all or nearly all parts of the globe, and that the elevation of these has been always accompanied by convulsions. Instructed by the discovery of the effects of these rocks upon adjoining substances, we may now proceed to inquire into certain phenomena, of much more extensive occurrence, but of nearly a similar character, and which appear due to the pervading action of heat upon stratified rocks since their deposition.

Ratio of the Metamorphism of Strata.—On reviewing the series of strata in relation to the degree of their metamorphism, it is impossible not to perceive that this increases continually with the age of the rock; so that, taken as a group, the primary systems of gneiss and clay slate, with all their modifications, are far more altered than the other strata, while the tertiary strata are the least altered of all. The same result is obtained by more minute comparisons of analogous rocks, the slates, shales, and limestones of the primary series, with the shales, and clays, and limestones, and marls of the secondary and tertiary strata. A plausible cause for the superior consolidation of the earlier strata seems to offer itself in the greater pressure to which, it may be imagined, the lower strata have been subjected; but this is not sufficient to account for the whole effect of consolidation, and is directly negatived by the numerous joints and fissures, which indicate lateral rather than vertical contraction of the strata. The lowest strata are, besides, not merely in a high state of consolidation; some of them, as primary limestone, display in a most decided manner that crystalline structure which results from heat; others, as clay slate, are fissured in such a way as is known to have been locally occasioned by the heat communicated from igneous rocks; others, as quartz rock, show clear proof of having undergone, if not actual fusion, at least such an agglutination of the grains as can be produced by art in a furnace. The conclusion from all this is of great importance; for as these rocks are of almost universal occurrence below all the other strata, and their characters are not referable to the local proximity of igneous rocks, we are assured, taking into account the subjacent granitic rocks, of the almost universally pervading influence of subterranean heat.

Alterations of Primary Strata.—It is impossible at present to point out exactly the amount of changes which have been produced on the primary strata by the general and continued communication of heat from below; because, with respect to some of them, it is difficult to feel very confident of the precise state in which they were deposited by water. With respect to gneiss, for example, which is in some cases almost identical with granite, in other cases approximates to sandstone, it is hard to say how much of its granitoid character is due to subsequent metamorphism; because we have no certain means

of knowing the degree of movement to which its ingredients had been exposed in water. Yet when we consider the bedded and laminated character of this rock, and observe that its constituent minerals, even when united into a dense rock, are not crystallized with regular external forms, successively modifying one another in a certain order, we seem to understand that the rock has been solidified by a species of imperfect fusion at the edges of the constituent substances, which, carried to extreme, would have reconverted the whole to granite.

Similar remarks apply to mica schist, which, on the one hand, varies to gneiss, and on the other to clay slate; and it is observable that the fusible mineral garnet, which is known to have been generated at moderate heats in contact with trap, is very generally intermixed with the laminæ of gneiss and mica slate.

If we rise to the contemplation of the carboniferous system, we shall be able to trace in the generally high state of induration of the sandstones, shales, and limestones, and in the frequency, systematic direction, and continuity of the joints, clear evidence of the action of heat. But yet we perceive that these effects of heat are not nearly to the same degree as those in the primary strata. A simple proof of this is afforded by the limestone of Teesdale, which is a hard rock, but which, where it touches the basalt of that country, has been subjected to nearly the same change as that observed in primary limestone: it has become crystalline. The shales are also altered and prismatized (fig. 95, p. 164). The upper portions of the slate system in Shropshire and Radnorshire, where that system is immensely thick, show the same changes.

Decreasing Effects of Heat in Newer Strata.—The effects of general heat continually decrease among the superior strata of the saliferous, oolitic, and cretaceous systems, and seem almost wholly lost in the tertiary strata. It is chiefly to this graduated effect of heat that we may ascribe the distinctness of the rocks in different parts of the series. Thus to take the calcareous rocks, we have a gradually changing series proportioned to their antiquity, from crystalline primary limestone, through highly condensed carboniferous limestone, to compact lias, concretionary oolite, marly chalk, and lacustrine marls. Among sedimentary deposits there is a series from gneiss through the hard sandstones associated with the carboniferous limestone to the sands of the oolites, chalk, and tertiaries; and another from cleavable slate, through jointed greywacke slate, hard coal shale, compact red marl, and clay of the oolite, chalk, and tertiaries. There is properly no sand, clay, or marl among the older strata. Indurated shale, hard gritstone, and solid limestone are of rare occurrence among the younger.

It does not appear that the occurrence of ironstone, pyrites, gyp-

sum, &c., in detached masses among the stratified rocks is to be considered as in any direct or exclusive manner due to the influence of heat, but rather to the ordinary forces of molecular electric attraction operating during or after the deposition of the mingled mass of matter. The spar veins in septaria have undoubtedly been filled since the concretion of the clay balls, and for the transfer of the calcareous or siliceous matter we must appeal to the same processes which have filled the cavities of shells and many cracks in limestone rocks with the same materials. No doubt in these effects an elevation of temperature might modify and perhaps accelerate the results, but it would be ridiculous, at present, to adopt Dr. Hutton's notions on some of these subjects.

Effects of Heat on the Deposition of Strata.—The preceding examples show clearly the effect produced on strata by the action of heat since their deposition. There can be no doubt that the same powerful agency must, especially in the earlier eras of geology, have greatly influenced the manner and circumstances of their deposition. On this subject, however, we have not at present much to record, and that little is wholly confined to the primary series of strata. There is one leading fact often connected with the stratification of gneiss, mica schist, &c., and not seldom repeated in chlorite schist and clay slate, which seems wholly unexplained by the direct action of heat upon these strata. The *contortions* of the laminæ of these rocks are very remarkable, and, if not coeval with their first formation, may, perhaps, be locally related to axes of elevation, as in the district of Loch Lomond.* In some instances Dr. MacCulloch thinks they are most numerous where quartz veins penetrate the rock. These contortions may, perhaps, be understood by comparing them with some analogous cases in laminated sandstone, where the undulations and confusion of the laminæ indicate agitation in the water. If we allow that the water in which gneiss and mica schist were formed was heated to a great degree by contact with or proximity to the sources of subterranean heat, the agitations of the ebullient liquid might, possibly, give to the strata then forming under it the very peculiar character of minute and irregular undulations which so often belong to these ancient rocks. Mr. Sharpe regards the foliation of gneiss generally as due to metamorphic action of the same kind as that which produced cleavage in slate.

Deposition of Limestone.—Another thing apparently characteristic of the mode of deposition of the primary strata is the isolated condition of the limestones which interlaminate the schistoze rocks. How different in this respect are the detached often lenticular primary limestones of Scotland, and even the transition limestone of

* Duke of Argyll, in Geol. Proceedings, 1853.

Devonshire and Wales, from the regularly continuous calcareous beds of lias, oolite, and chalk! Is it not very probable, that some local efflux of gases or the influence of local centres of heating agency have sometimes performed the same effects as coral animals, and determined to particular points the extremely limited decomposition of the ocean water which undoubtedly was the source of the limestone deposit?

Ancient Climate.—The earth is still hot below us, but the warmth communicated to the surface from the interior of the globe is very small, less, probably, than 1-10th of a degree of Fahrenheit.* This arises from the low power of conducting heat which the strata in the earth's crust possess, and from the waste of heat at the surface, by radiation into the cold ethereal spaces which surround our planetary system. Were the earth's atmosphere wholly removed, so as to allow of a free, instead of a much impeded radiation into space, the temperature of the surface would sink, and the interior isothermals retreat downwards. Were the atmosphere augmented in volume and density, and more filled with that cloudy envelope which now stops and returns some of the escaping heat, the surface would be warmed and the isothermals rise in the rocks.

Again, were the conducting power of the rocks augmented near the surface, which perhaps would happen if their temperature were raised, the isothermals, though they might not rise, though even they might be depressed, would communicate heat to the surface.

These circumstances must not be overlooked in statements bearing on the question of the possible influence of the exterior heat of the earth, on the climate of early geological times. If, in those times, the solid crust of the earth were thinner, and given isothermals (100°, 200°) were nearer the surface than now, the climate must have been affected. The problem scarcely admits of numerical expression, but we may take it between two limits. First, we may suppose the waste of heat at the surface not greater than at present. In this case, *no more heat need flow upward*, and the surface would be warmer by 10°, if the isothermals were higher by only 600 feet, so that the heat of boiling water, which is now believed to be about 10,000 feet deep, would then have been met at about 9,400 feet. Secondly, we may suppose the waste of heat at the surface augmented in proportion to the increase of the temperature of the surface. In this case, to warm the surface 10°, one hundred times *more heat must flow* from the interior to repair the waste, and this would require a corresponding rising and crowding together of the isothermals, so that the temperature would increase about 1° for every foot of descent, and the heat of boiling water be found at

* Poisson supposes the surface to be warmed only 1-30 of a centigrade degree, by communication of heat from the interior.

100 feet. Neither of these cases can be true, but between them the truth must lie.

In estimating between these extremes, we must remember, that in whatever degree the mean temperature of the earth's surface should be exalted, the quantity of moisture which would be thereby raised into the atmosphere would be augmented in a much higher ratio. An addition to the mean temperature of 10°, would add about 4-10ths to the mass of aqueous vapour in the atmosphere, and augment in a still higher degree its cloudiness, and that power of diffusing the escape of heat, which is one of its most valuable functions. It follows from this reasoning, that a higher temperature might be imparted to the earth's surface in ancient geological periods than we experience now, because then the globe had undergone less of that refrigeration which is still in progress, and isothermals of given thermometric value were nearer to the surface. The climate would also be more equable, as being less directly dependent on the sun, and perhaps as having more generally the oceanic character, which is precisely what the most probable inferences from the study of organic remains suggest. In the palæozoic ages, especially, the preponderance of ferns (including arborescent kinds) on the land, the abundance of reef-making corals and Crinoidea in the sea, (the evidence going as far north as Christiania, Baffin's Bay, and Melville Island,) would require such a climate. In the mesozoic ages, Zamiæ on the northern lands, Astræiform madrepores in the sea, and gigantic reptiles in the sea, in the rivers, and on the land, require such a climate. Nor is the evidence quite lost in cainozoic times, but continued in the nipadaceæ of Sheppey, and the crocodiles of Hordwell.

Those who refuse assent to this doctrine, and yet accept the probability of the higher surface temperature of palæozoic ages, may choose between two other modes of explanation, which equally involve postulates not admitted in physical science. They may, if they can, displace the axis of rotation of the earth, or magnify beyond all belief the existing agencies of climatal change at the surface. The former task we leave to any geological Sisyphus who finds enjoyment in such labour; the latter deserves at least one remark. If we estimate the former temperature of the northern palæozoic sea, and mesozoic rivers, by the climate of modern coral reefs and the haunts of crocodilian reptiles, we must be prepared to add 15° or 20° to the mean temperature experienced in these latitudes and longitudes. Now the mean temperature already and actually experienced in the longitude of Britain and Norway is the highest by many degrees (10° to 20°) in the whole circle of these latitudes. In other words, this region now experiences the full effect of the warming surface influences communicated by winds and

waves from the equatorial zones; and sound reasoning forbids us to assume for *such* influences in ancient times so violent an augmentation of their power, as to more than double their effect. But if even this were done, it would answer no good end, since beyond these longitudes, in the north of America, the same evidence of ancient high temperature in the same periods, would require the hot streams of air and water *there*, which were already in demand for the equally exigent climate *here*. This appears to us an insuperable objection, one not at all obviated in the ingenious hypotheses of Lyell, or the diagrams of the positions of land and sea, which (he thinks) might produce the extremes of heat and cold in the climates of the globe.*

It is a curious proof of the changing aspect of geological reasoning, that we have been lately busy in finding out the best process for cooling the northern temperate zone, so as to allow of the formation of thick glaciers on Snowdon and Skiddaw, the Mourne mountains, and the peaks which look over Killarney. For in the pleistocene period, these were all mothers of glaciers, and delivered icebergs to a glacial sea (p. 419 *et seq.*) To account for these phenomena, we need not, and, indeed, must not adopt the Lyellian view of continental displacement, already referred to, but simply assume the temporary suppression of those causes which now elevate above the average the mean temperature of Britain, and a temporary substitution of conditions which, like those now observed in Tierra del Fuego, lower the summer heat.

In the latitudes of 50° and 60°, the western shores of the old world are warmer than the eastern shores of the new world by 12° to 18°. In fact, the Gulf Stream, and the system of south-westerly winds, both flowing from the warm equatorial regions of the Atlantic, bring to our shores and the oceanic border of Scandinavia, the mildness of southern climes. They flow hither for physical reasons, they are a part of the circulating current by which life as well as heat is distributed over the varied globe, and they are compensated by return currents in other regions. Change the bed of the Atlantic, open by a general depression new channels to the northern basin, as, for example, from the Gulf of Mexico up the great valley of North America,—let the warm stream take this course towards the pole, the mean temperature of Europe, and particularly the west of Europe, would be lowered, it may be, to 10°. Such a general depression of temperature would be heightened in its effect upon the accumulation and permanence of snow in Britain by a reduction of summer heat; for on this, and on peculiarities of the ground, mainly depends the height of the line of perpetual snow. Such a lowering of summer

* Principles of Geology, book i., chap. 7.

temperature would happen if our islands were depressed; such a depression did happen in the pleistocene period to the depth of 1,500 feet. Thus by known causes and conditions ascertained to have occurred, or rendered very probable, we find the mean temperature on the top of Snowdon reduced from 37°, at its present height of 3,750 feet, to 32°, at the lowered level of 2,200, a condition in which glaciers would be possible. If to this effect, which is merely that of the abstraction of the Gulf Stream, and the depression of the land, we add the probable influence of an entirely different system of winds, and a cold arctic return current, such as the marine fauna of the period indicates, there is evidently cause enough for the *permanence* of those snows on our mountains, which now fall *at intervals* with such severity in our winters, and that boreal cold which chills the breath of May and blights the roses of June.

We have here given, in few words, the general idea which this subject obviously suggests. It has been well and amply worked out by Mr. Hopkins* on the excellent basis of Dove's Maps of Isothermal Lines, a publication of the highest value to every branch of physical science.

Atmosphere.

Moisture.—The effects of a cooling globe cannot have been insensible on the atmosphere. Without taking into account any earlier possible condition of this aerial envelope—without tracing the history of the great volumes of water from that almost unimaginable state of vast and violent rains which Mr. Babbage marks as one of the early phases of our planet†—starting with a merely thermal ocean, and a generally higher terrestrial surface temperature—we cannot doubt that the air would be more humid,—the precipitations of frozen and unfrozen‡ moisture more abundant—the river action more violent. Under such circumstances alluvial phenomena, such as our coal measures appear to indicate, would proceed at a more rapid rate than is usual in the present aspect of the earth's surface. We should not forget this while reasoning on the subject of geological time.

Carbonic Acid.—Under great heat, many bodies part with gas; even if chemically combined with them, others yield up what they have by some molecular force retained in their tissues. One gas in particular, which enters largely into the constitution of very extensive rocks, and by its decomposition yields now the substantial fabric of plants, seems to have been far more prevalent in the atmosphere in early geological times than it is now. This is carbonic acid, which

* Geol. Proceedings, 1853.

† Ninth Bridgewater Treatise.

‡ Rain is more frequently melted snow or hail, than hail is frozen rain.

constitutes at present $\frac{1}{1000}$ part of the atmosphere by weight. Were this seemingly small dose of that gas removed, the vegetable world would fade away; the animal creation perish for want of food; and the populous earth become a desert. So finely balanced by the Almighty are the issues of that life which he has appointed, and which he sustains. But let us suppose the dose augmented, and the atmosphere be both warmer and damper, as it was in the palæozoic condition, if we rightly understand the history of the globe. What might be expected from such conditions? Obviously, a very abundant growth of those families of plants which love warmth and moisture—such as the ferns, which have been long remarked as furnishing the most numerous groups of fossil plants, especially in the later palæozoic ages.* Dr. Daubeny's experiments confirm this reasoning.†

In respect of the quantity of carbonic acid in the atmosphere in the precarboniferous ages, there can be no question that it *was* very much greater than in any later time. For not only are we to count upon the vast quantity of carbon which, derived from atmospheric carbonic acid, has been fixed in the palæozoic coal, for the advantage of the period of man, but we must also add to this a portion at least of the enormous quantity of the gas which is fixed in the palæozoic limestones. The coal of Britain alone, counting only what comes to the surface, contains carbon enough to add one-fifth to that now existing in the whole atmosphere: we may afford to suppose that all Europe will yield no more, but North America overmatches many times all the carboniferous tracts of the old world. (See page 217.)

We thus arrive at two probable stages in the condition of the earth's surface—early stages, but not the earliest. During the supposed period of excessive aerial moisture, it is inconceivable that life should exist; at some later period the abundant vegetation of a warm, moist climate. Brongniart, to whom we owe this ingenious view of the effects of a former state of the atmosphere, adds the remark, that such a state of atmosphere so favourable to the growth of ferns and some other plants, would be as unfavourable to the life of air-breathing animals; and points, for confirmation, to the almost total absence of such animals in the palæozoic periods. Since he made the remark, some reptilia have come to light in the Devonian carboniferous and permian strata. They are still few, and it must be remembered that they are reptilia, that is to say, animals less than others delighting in the purer atmosphere. Some insects have also been found in the coal formation.

* Lindley's experiments (Fossil Flora, vol. iii.), are often appealed to, as proving that this large proportion of ferns in the coal formation, only shows that such plants abound in a fossil state because they better resisted the decay caused by immersion in water. But the circumstances of the experiment are not those of nature.

† Reports of the British Association.

The palæozoic limestones contain abundance of marine, and probably a very few estuary shells. These do not, perhaps, in the smallest degree militate against the view of M. Brongniart, for they breathed the air *contained in water*, and the vital air and carbonic acid taken by absorption into water, are not to be judged of either as regards quantity or physiological effect by the proportions in which they exist in the atmosphere above. After the palæozoic ages we have animals augmenting in variety and number; pulmoniferous creatures of many races; but never again that vast and wonderful abundance of terrestrial plants, which, for many centuries to come, will, we hope, fully supply our hearths and manufactories, hurl the thunderbolts of war on the enemies of man, and spread over the world the products of industry and peace.

376. Conical Boulders (Arran).

CHAPTER XX.

STATE OF GEOLOGICAL THEORY.

A review of the preceding pages offers abundant proof that geology has *escaped* from that critical stage through which all sciences, founded on observation, must pass—the stage of speculation and dogmatism. If it has not yet arrived at the dignity which is conferred upon the highest forms of inductive science, by the establishment of very general laws, binding together a mass of dependent phenomena, it is enriched with many valuable generalizations, provided with powerful means of further investigation, and guided by distinct landmarks over a wide field of original discovery. Geology is dissociated from cosmogony, and we are no longer made to perplex our minds with "thoughts beyond the limits of our frame," no longer required to accept an explanation of natural phenomena, founded on a violation of the laws of nature. Leaving the impossible problem of the creation and first disposal of the matter of the earth to those who may think there are means of solving it, but ascending beyond the short annals of the human race to the contemplation of the earlier epochs of the world, geologists endeavour to discover the series of revolutions which have affected the earth, by deciphering the monuments which they have successively left.

Men may be as soon reclaimed from barbarism, and raised to the summit of civilized excellence, as philosophers induced to abandon the sweet paintings of theory for the hard outlines of fact; and though in the successful career pointed out and followed by the Geological Society of London, the principle of fact before theory has been generally acted upon, it is difficult to repress the impatience which would rather mingle truth and fiction in a bold conjecture, than patiently separate the gold from the dross by the regular process of analysis. The opinion has been expressed by high authority, and seems to be gaining ground, that the time is arrived for the intervention of theory, to arrange the vast mass of facts which at present constitutes positive geology, and to indicate the lines of further progress toward higher points of knowledge. It is, however, to be supposed, that few will obey this premature call for theory, who are aware of the many unfinished inquiries and vague generalizations which must be settled before even a prudent speculator would venture to commit himself to the tribunal of inductive philosophy.

State of Geological Theory.—We have now assembled many data for a theory; but in the very labour of collecting them, men have gradually acquired what is more valuable, a habit of limited general-

ization, and of continual appeal to the progress of collateral evidence in unfolding the laws which govern material nature, which at once restrains the presumption of the writer and the credulity of the reader. Under these circumstances the progress of the science is not doubtful, and all that can be reasonably attempted toward the foundation of a theory of the earth, is a review of the bearing of the facts already ascertained, on some of the leading problems involved in geological speculations: we shall thus learn what knowledge we have gained; what inferences it will support; how that may be augmented, and these corrected.

Lapse of Time. Geological Chronology.

All the thoughts of men are so inseparably associated with the idea of succession, that the knowledge of any physical fact is never satisfactory unless the *time* of its occurrence be given. The historical period of an occurrence is determined by reference to other events, whose place in the series of recorded human actions, or natural processes, is known. The chronology or fixing of the year in which any event took place is an admirable contrivance, the fruit of enlarged science, which has found the means of referring all historical events to an independent and permanent natural scale, the movements in the solar system. No person proceeds many steps in geology, without feeling the want of some historical scale of successive phenomena, in which to interpolate new terms of the series; and though this want is to a certain degree generally, and for particular regions of the globe perfectly, supplied by tables of the superposition of strata, we still find ourselves impelled to attempt the reduction of this historical series to the independent scale of chronology.

This difficult problem has never been fairly entered upon, except in the particular case of the diluvial and alluvial deposits. Those who admit the identity of the diluvial or glacial currents of geologists and the Noachian flood, and suppose, with Cuvier and De Luc, that this was "the last great revolution affecting our globe," may be expected to feel some anxiety as to the number of years which on natural, that is to say, geological evidence, can be reasonably supposed to have elapsed since that event. In such inquiries the growth of the deltas of the Nile, the Po, and other rivers, the movement of the sands of Libya, the excavation of river courses, may all be employed according to the views of the writer.

Superficial Deposits.—Always it is to be remembered, these calculations admit as a principle the uniformity of natural superficial agencies since the diluvial period, and that period is geologically defined with more or less certainty. From such data consistent

results seem attainable. There are, however, difficulties in estimating the amount of mechanical effect performed, not easily overcome. In the case of a delta the materials may have fallen into water of unequal or unknown depth, and have been exposed to waste by currents of variable force. The movement of sands must be yet more capricious. The time employed in the recession of the falls of the Niagara from Lake Ontario toward Lake Erie has been estimated by Lyell at 10,000 years, by Fairholme at 5,000; 5,000 or 6,000 years is the vague conjecture, rather than conclusion of Cuvier, of the time elapsed since the "last grand catastrophe;" and in general it must be owned that the methods of arriving at these conclusions have very little of accuracy to recommend them.

Those geologists who admit the excavation of valleys by a force of water greater than what now passes down them, may take the date of the denudation of these as an era, and compute the time elapsed in the subsequent excavation of the river bed, in the partial or complete filling up with sediment of lakes along its course, and in the retrocession of waterfalls along the main or branch streams. Few persons, however, who value an arithmetical result for its precision, will proceed to the calculation without more information of the *rate* of these operations than is at present attained.

The fossil elephant, and other animals whose remains lie buried in gravel and other glacial deposits, belonged to a system of organic life which, for some limited period prior to and during the era of those deposits, was established over a large part of the surface of the northern hemisphere. This is termed by many geologists the antediluvial period; some intending by this nothing more than to mark its relation to the era of the "diluvial" currents, thus adopting the term from comparison with Scripture history. This is, properly, a terrestrial period; and we have shown the difficulty of defining its limits towards the tertiary period, which is, principally, a marine period. The lacustrine tertiaries here become almost our only safe guides; and they teach us that during the tertiary period an earlier group of extinct animals, the palæotheria and their congeners, inhabited the same tracts of the globe as those which afterwards nourished the mammoth and mastodon. We are absolutely without any means of estimating in years the length of the interval between the era of the palæotheria buried in the Paris basin, and that of the elephants which are entombed in gravel deposits.

If the difficulties experienced in attempting to chronologize the terrestrial phenomena of the later geological periods have been sufficient to deter nearly all prudent and exact writers from venturing to give more than an illustration of the kind of reasoning to be employed, it is no wonder that for the long series of successive marine strata the attempt has been almost absolutely abandoned. It

is doubtful whether we ever shall arrive at more than plausible inferences concerning the *time* elapsed in the production of the stratified rocks; yet as the consideration of this subject can be prosecuted in a strictly philosophical spirit by the help of several satisfactory analogies, and as at all events the historical succession of the phenomena is either perfectly known or capable of becoming so, it appears an equally useful inquiry as that relating to the subsequent terrestrial periods.

Old Stratified Deposits.—To determine the length of years required for the deposition of all the stratified rocks under the circumstances in which they are observed requires a knowledge of the number of repetitions of similar phenomena, and of the *rate* of their occurrence. In the geology of stratified rocks several independent series of phenomena occur, each of which may be subjected to this examination. Of these we may notice:—

1. The mechanical deposition of sands, clays, conglomerates, &c.
2. The chemical deposition and vital accretion of limestones.
3. The periodical alternations of the laminæ or strata of clay, sand, limestone, &c.
4. The growth and decay of organic beings then living in the sea.
5. The successions of races of organic beings in the same parts of the ocean.
6. The succession of convulsions.
7. The alternation of marine and fresh water productions.
8. The alternation of marine and igneous products.
9. The metamorphism of rocks, fossils, &c.

1. Mechanical deposits of sand, clay, &c., take place only in consequence of degradation or waste of some region of the globe, followed by a removal of the materials to some place of comparative tranquillity. Intermitting actions of this kind usually produce laminated deposits, and if the materials be of different kinds these may alternate in the sediment. In some valleys every inundation leaves a thin layer of sediment: the number of inundations might thus be counted since any given date, and the number of years nearly ascertained. Analogous effects happen along those coasts where the tides deposit sediment. We see the same effects in many of the sandstone and clay strata which were accumulated in estuaries.

Estuary Accumulation.—Taking as an example of the latter class of deposits the Wealden formation, and allowing it to occupy 3,000 square miles, and to be 800 feet thick, we may ask what period of time was consumed in the production of it by a great river. The Ganges is such a stream. It drains 300,000 square miles. It transports matter from every part of this area; so much, according to actual measure, as to indicate an average waste of the whole area of 1-111th part of an inch in a year. Applying these data to the Wealden formation, we find 10,000 years required for the accumula-

tion of the earthy matter by the operation of this great river. At the same rate the coal formations of Britain, supposing them to be 10,000 square miles in area and 5,000 feet thick, would require 240,000 years to be collected from the waste of 300,000 square miles.

Some of the flagstones of the coal measures are composed of frequent alternations of rolled grains of felspar, quartz, and mica, which may be estimated to occupy not more than one-twentieth of an inch in thickness. Taking the thickness of the rock at 40 feet, we shall have 9,600 layers, each of which marks *an interrupted action.* Let this be supposed to be the tide, allow that every tide deposited one layer, equal to about 700 per annum; this will occupy 13½ years. As far as we can ascertain, the other sandstones of the coal tract were accumulated in the same manner, though only a few of them are micaceous enough to show this minute lamination. The thickness of the Yorkshire coal measures is about 3,000 feet. Half of this may be considered as sandstone equal to 1,500 feet, which, according to the above calculation, might be deposited in about 500 years. If we suppose the accumulation of the alternating clays to have been at the same rate (there is good reason to admit this), the whole period occupied in the deposition of the earthy parts of the coal measures would be 1,000 years. This computation contrasts strongly with that derived from the growth of land plants on the spot; for if this were the process by which coal was formed, and the rate of growth were the same as in the area of Europe, we should require above 2,000 years to make a bed of coal one foot thick, and more than 120,000 years to yield the 60 feet of coal common in Britain.

Mechanical Deposits.—It is perhaps unnecessary to say, that the assumption of each lamina marking the action of one tide is perfectly gratuitous, and has been adopted merely to give a specimen of the mode of calculation which must be employed if we wish to state the probable extent in years of a given geological period. Conglomerate rocks present a most convincing proof of the considerable periods which sometimes intervened between the deposition of two stratified rocks in contact and immediately succeeding one another. These rocks of turbulent origin are locally distributed, so as to be in some parts enormously thick, and in other places almost or entirely deficient. The old red sandstone conglomerate, for example, usually separates by a great thickness the Silurian strata from the superincumbent carboniferous limestone. In Herefordshire and Radnorshire this series of red sandstones and conglomerates is many thousand feet thick; but in the greater part of the Cumbrian mountain tract it is absent, and the limestone and slate are in contact. In this case, it would be a great error to suppose the deposition of the

limestone to have been immediately consequent on that of the slate. In fact, that very district gives proof that a period of violent watery tumult intervened, during which the slate rocks were broken up and rolled to pebbles, and reconsolidated into a thick conglomerate. The rate of this process can only be conjectured, by comparison with the production of pebbles by the diurnal processes of tides, rivers, and local inundations. When, as in the Righi, we find rolled masses of conglomerate containing rolled pebbles; in the old red conglomerate of Cumberland masses of the preconsolidated slate; in the new red conglomerate of Westmoreland fragments of the mountain limestone with organic remains which have undergone *their usual chemical conversion;* enough is known to prove, to a mind not wholly blinded by false views of science, that the monuments left for geology to decipher carry back the history of the earth to periods when man and his works existed only in the long foreknowledge of his Maker.

2. **Chemical Deposits of Limestone.**—It is difficult to fix upon any method of estimating in years the time required for the deposition of a given mass of limestone. It is useless to refer to instances of the production of limestone from springs, in fresh water lakes, in estuaries or coral reefs, unless the circumstances under which the older calcareous deposits took place were similar, a case seldom to be proved. The following process, founded on the statements in p. 65, appears the least objectionable.

It is certain that while the sandstones, shales, coals, and thin oolitic limestones of the North York moors were deposited upon the lias, a deposit almost wholly calcareous was occasioned near Bath. The whole time consumed was the same in each locality. We may, therefore, perhaps infer the comparative rate of deposition of the oolite and the sandstones. The total thickness of the mass in Yorkshire is about 750 feet, of which about 20 may be called limestone; of that near Bath 480, of which nearly half is sand and clay with calcareous matter interspersed. Hence we have the proportion of three feet of sandstone deposited in the same time as one of limestone.

Another instance is afforded by comparing the sections of the lower carboniferous limestone, in Derbyshire and in Tynedale. In the former tract we may take 750 feet as the thickness of limestone, with no admixture of sands or clays; in the latter, the contemporaneous strata are at least 1,750 feet thick, and contain 367 feet of limestone, and 1,283 feet of sands and clays, &c.; consequently, 383 of limestone correspond in time to 1,283 of sands, clays, and coal, or 1 to 3·3.

3. Alternation of chemical and sedimentary deposits.—There is undoubtedly a periodicity in these alternations, but we are not yet

in a state to draw any inferences, as to the cause of the recurrences, much less as to the length of their periods.

4. **Organic Remains.**—Embedded organic remains.—In viewing the shells distributed in rocks, we sometimes perceive, amongst a large collection of them from a given stratum, a complete series of forms from the youngest to the full grown shell; and this may be a means of calculating the lapse of time during the accumulation of a given thickness of rock more exactly than by any other. A thickness of calcareous shale, not exceeding one foot in the Yorkshire coal field, holds individuals of goniatites listeri of every magnitude between a pin's head and an orange; it is not to be doubted that they lived where they are found; and as not one example of this species is known in any other stratum in the neighbourhood, it seems correct to admit that, during the deposition of that small mass of shale, so much time elapsed as to allow of the growth to full maturity of a long-lived cephalopode. The only other supposition which can be entertained, is that they were introduced alive by a transient irruption of the sea into a fresh water basin, and there quickly entombed.

It is to be regretted that the age of shells has been very little inquired into among collectors. Both conchifera and mollusca are probably, in general, long-lived animals.

The immense number of shells occasionally buried in a rock is sometimes appealed to as a proof of the length of time consumed in its production; but this is a very unsatisfactory argument. Those who have witnessed the amazing increase of cyclas rivicola in the canal near Leeds, or of uniones and anodontes in many sluggish rivers near the tideway, or have walked among the numerous shells on the coast of Ayrshire, or the crowds of tellinæ thrown upon the Filey sands by a single tide, will not permit to geologists the use of such a fallacious inference. This immense abundance of fossils is often a local phenomenon in the rock, and one which, when better understood, will aid materially our conceptions of the agencies which were concerned in its accumulation.

The nearly vertical position of certain fossil plants, a phenomenon by no means rare among sandstone rocks, affords good ground for caution in assigning very great extension of years to geological periods. The stems of equiseta in sandstone of the oolitic era, (p. 297,) of sigillaria in sandstone of the coal series, (p. 212,) of dicotyledonous wood in limestone of the isle of Purbeck, seem to teach us in plain terms that the accumulation of these rocks was not of that slow and insensible kind which is often attributed to them. Whether we suppose them to be in their place of growth, or to have been swept down to their present situations by land floods, the result as to our present argument is the same; the accumulation of transported sediment must have been so rapid as to prevent the de-

composition of the cortical portions of the plants, the wearing away of the superficial structure, or the bending of the stem beneath currents of water. No one doubts that the bed of stone three feet thick, which encloses equisetum columnare at High Whitby, was laid by a single inundation; we will suppose it an annual occurrence; the other sandstones and shales of this series must have the same rate of origin ascribed to them; this would give for the formation of the oolitic sandstones and shales in the North York moors a period of 150 years. About the same, or a slower rate of formation, may be supposed for the case of sigillaria in the coal sandstones of Yorkshire; for these stems, when above two or three feet long and nearly vertical, pass through more than one, sometimes four or five beds of stone. (Altofts near Wakefield.)

5. **Succession of Races.**—Successions of races of organic beings in the same parts of the ocean.—The succession of different races of organic beings in the same parts of the ocean, is one of the leading facts which speak the most impressive, though not the most exact, language on the subject of the long duration of geological periods. For, whether we consider those cases in which the extinction of old and the introduction of new species was gradual, or others when the changes were sudden and complete, nothing that we know of the actual constitution of nature will justify us in admitting that these revolutions in the animal world followed quickly one after another. We are impelled to conclude that, for the existence of any given race, consisting of thousands of individuals, of many hundred species, embedded in many different kinds of rock, in distinguishable groups according to their habits of life, a long time must be allowed, or else the whole constitution of nature was in a state of forced acceleration, so that the work of ages was crowded into years. Whether we suppose that new species were contemporaneously created in all the situations where they lived and died, or distributed from one local origin over the sea, or transported by currents from other oceanic centres of life, no one who considers the stability of the actual system of watery life, will be easily persuaded to believe that these prodigious changes were operated over a large part of the globe in times that can be included within such narrow limits as those of human experience. Yet who will venture to translate the vague and almost poetical visions of long duration, which the contemplation of many repetitions of these local revivals of nature so powerfully awakens, into the language of chronology? It is evident that the day has not yet arrived, or rather it is gone by, for dogmatizing about the antiquity of the crust of the globe.

D'Orbigny admits, as the result of his own studies in palæontology, no less than twenty-seven successive stages of stratification—ages of the world—containing each a special and peculiar fauna. Including

only the mollusca and radiata, he presents 18,206 species, whose distribution is stated as follows, in five grand divisions. (Terrains.)

Terrains.	Stages.	No. of Species. In Stages.	No. of Species. In Terrains.
Tertiary	27. Subapennine	606	6,042
	26. Falunian, Upper	2,754	
	26. Falunian, Lower	428	
	25. Parisian	1,576	
	24. Suessonian	676	
Cretaceous	23. Danian	66	4,291
	22. Senonian	1,579	
	21. Turonian	380	
	20. Cenomanian	849	
	19. Albian	410	
	18. Aptian	156	
	17. Neocomian	851	
Jurassic	16. Portlandian	60	3,846
	15. Kimmeridgian	199	
	14. Corallian	655	
	13. Oxfordian	739	
	12. Callovian	281	
	11. Bathonian	546	
	10. Bajocian	603	
	9. Toarcian	288	
	8. Liasian	301	
	7. Sinemurian	174	
Triassic	6. Saliferous	792	927
	5. Conchylian	135	
Palæozoic	4. Permian	91	3,180
	3. Carboniferous	1,047	
	2. Devonian	1,198	
	1. Silurian, Upper	418	
	1. Silurian, Lower	426	
		18,286	18,286

If to these we add the vertebrata and articulata, the total number of known fossil species would be about 24,000. "Twenty-four thousand facts," says D'Orbigny, which establish the succession in all parts of the globe of as many distinct groups of animal life, following one another in a settled order of geological time.*

Confining our attention to the vertebrata, we may represent the *rate of change* by a diagram like the following:—

* Cours élémentaire de Palæontologie et de Géologie, tom. ii., p. 250-251.

PERIOD OF MAN

Cainozoic, or Tertiary Life Periods.	Megacerian Mammothian Palæotherian	Ages of Extinct Mammalia.
Mesozoic, or Secondary Life Periods.	Mososaurian Megalosaurian Teleosaurian Palæosaurian	Ages of Extinct Saurians.
Palæozoic, or Primary Life Periods.	Palæoniscian Megalichthyan Pterichthyan Palichthyan Proichthyan	Ages of Extinct Fishes.

PROZOIC? PERIOD.

In this table, the elements of thickness of the several great groups of strata is introduced; it shows the *greater thickness of strata* corresponding to a given *change of life*, in the early than in the later ages of the world. If we measure geological time by thickness of strata, the changes of life have been most rapid in later periods; if we take life-changes for our scale of time, mechanical agencies were more active in early periods. This latter conclusion is most in harmony with the general views adopted in this treatise.

6. The successions of convulsions in the same physical region may be very properly mentioned as a vague indication of the lengths of geological periods; but cannot at present be employed in a more exact manner to determine their duration.

7. The alternation of marine and fresh water products is another of those grand phenomena, which, whether rightly or not, is sure to make a deep impression on the mind; though the rarity of the case, and our ignorance of the principal efficient circumstances, must wholly exclude it from among the data for accurate calculation of geological time.

8. The same may be said of the alternation of aqueous and igneous products.

9. The metamorphism of rocks, &c., in consequence of the local or general effect of heat, may possibly one day be sufficiently understood to permit some attempt towards determining the intensity and rate of the communication of heat, and thus more or less directly bear upon the question of time. The chemical changes of organic remains are evidently less related to time than to other circumstances, such as, the original nature of the body, the sort of substance in which it is embedded, and proximity to sources of mineral impregnation, whether by aqueous or igneous solution, or electrical transfer of solid ingredients.

Successive Conditions of the Globe.

The object of geological researches has been till lately very little understood by those not directly conversant with the subject; and even professed geologists do not always restrict their inquiries within just bounds. It is difficult for a speculator to believe that geology may become a very important branch of natural science, though it should wholly disclaim the investigation of problems concerning the creation or concentration of the matter of the globe, or the establishment of the laws of the universe. To know the successive changes which the globe has undergone, and thus to trace a retrospective outline of its successive conditions, is actually attempted by geology; but the very processes employed in this enterprise are founded upon the recognition of the existing laws of nature, and altogether exclude the popular notion of a chaos, and the philosophical hypothesis of an atmospheric expansion condensing to a solid globe.

Limitation of Geological Inquiry.—Undoubtedly the progress of legitimate geology teaches us that the same laws of nature have operated on this globe under very different circumstances, as to temperature, relation of land and sea, animal and vegetable life, and many other things; and it is become a proper problem for geology to discover these circumstances. In this point of view, the reflections of

Leibnitz, and the mathematical labours of Laplace and the astronomers, become of great value, since they help to fix conspicuous landmarks for the guidance of the surveyors in this large field of science; but let no one delude himself with the notion of discovering, by geological processes, the emerging of the harmoniously adjusted terraqueous globe from a former state of chaos. It is certainly not a philosophical, and surely cannot be thought a religious notion, that man shall ever discover among the works of God, the traces of a period when His Divine attributes were first awakened to rescue his creation from anarchy. Geology takes for granted the existence and collection of the matter of the globe, with its supernatant ocean, and its enveloping atmosphere. Except in the degree of influence which circumstances permit them to exert, it takes for granted the uniformity of action of all material causes. The investigation of miracles can never be admitted into natural science.

The dimensions of the globe have remained constant since the days of Hipparchus;* for Laplace has shown that the length of the day has not sensibly varied since that time, which must have happened if the diameter had perceptibly changed: if the globe had contracted, the diurnal period would have been shortened, and *vice versâ*.

This is usually considered a very formidable argument against the doctrine of internal heat, and its corollary, secular refrigeration and contraction, to which theorists have very freely resorted, as the prolific source of all subterranean movements, changes of superficial temperature, elevation of continents, volcanic eruptions, injection of igneous rocks, mineral veins, &c. Fourier's researches, however, into the mathematical theory of heat, show that, under the conditions of sensible constancy of dimension, and variation of superficial temperature according to solar influence, we are at liberty to suppose the existence of deep-seated heat of any intensity, provided there be direct indications of corresponding augmentation of sensible temperature below a certain depth. Such indications, it is very generally allowed, are presented by the observations in mines and collieries in Europe, Asia, and America.

Secular Refrigeration.—With regard to secular refrigeration, the experience of two thousand years undoubtedly shows that its effect in contracting the earth's diameter has been for that period insensible; but, first, it must be observed, that the hypothesis supposes the effect of refrigeration to be a contraction of an internal nucleus, and a consequent separation between it and the solid crust, which continually increases until the crust is broken or bent by a *convulsive collapse;* secondly, it is sufficiently evident that, by the accumulation of nonconducting materials over a source of heat, the diminution of

* Born 160 B.C.

this heat must become continually more and more slow, so as at last to be insensible even in very long periods. If, then, it should appear that the leading phenomena of the ancient history of the earth can be well explained by help of these suppositions, there is nothing in the mathematical theory to prevent their provisional adoption, on the basis, not unfrequently employed in natural philosophy, that they serve to explain many phenomena.

Volcanic Action.—It is by no means necessary to couple with the hypothesis of internal heat, the doctrine that volcanic action arises from this cause *only:* the various chemical characteristics of volcanic action must be examined upon their own evidence; and it does not appear that the hypothesis of particular chemical antecedents to volcanic operations is at all deprived of its applicability, or rendered superfluous, by admitting the existence of intense internal heat. On the contrary, under the influence of a high temperature, the admission of oxygen and water would still produce upon the fluid metalloids and metals the effects usually ascribed to such a cause, and perhaps more easily than if they were solid, and the results would still be proportioned to the circumstances of the locality.

Displacement of the Earth's Axis.—The moderation which geologists were so slow to learn, has prevented them from reviving the ancient speculation which ascribed the leading phenomena of geology to an extensive shifting of the earth's axis, and consequent displacement of the ocean. To be consistent, we must suppose this mighty operation to have been many times repeated before the occurrence of the deluge which it was invented to explain. Perhaps the *probability* that every part of the globe *equally* requires this displacement of the axis, but requires it in *different directions at the same time*, may be sufficient to prevent its resuscitation. It is too much, however, to treat it as an absurdity, merely upon the ground that the shells of equal density within the globe have their axes, at the present moment, nearly coincident with those of the surface; for, with this condition, irregularities do take place in the distribution of the exterior parts of the planet, as in the case of volcanic eruptions, and any material displacement of weights of the surface must (slightly) affect the axis of rotation.

Internal Heat of the Globe.—As Mr. Greenough has observed, "be the cause what it may, the fact is certain, that the temperature of the crust of the earth was higher when the coal measures were deposited than now, and we have reason to think it was still higher at antecedent periods. That a considerable degree of heat still exists, either partially or generally, at no great distance from the surface, appears from thermal springs and volcanoes." *

* Geological Society's Proceedings, 1834.

Origin of Terrestrial Organic Life.—In accordance with this view is the common opinion, that geological inquiries have discovered traces of a period in the history of the globe, when neither animal nor vegetable life was established upon it. This opinion, ably expressed by Dr. Buckland in his *Vindiciæ Geologicæ*, is chiefly supported by the facts observed in studying the lower palæozoic strata. The view of the subject which is most consonant to the course of inferences adopted in this treatise has been already sufficiently expressed in the review of the primary strata.

Whatever may be the truth on this point, it is certain that the successive systems of organic life, both terrestrial and aquatic, animal and vegetable, show the same general principles and relations as that to which we belong. Geology has disclosed various and remarkable animals, not paralleled in existing nature, and plants of singular forms, but nothing which deviates from those general laws of structure and function which govern the actual organic creation. The plants and animals of different geological periods do not differ more from one another than those in opposite climates, or even distant localities at present. There is even to be observed among the several successive systems of organic remains some real analogy to existing local faunas and floras. The oolitic fossils have, perhaps, a greater resemblance, for instance, to the living productions of Australia and the Indian islands than to those of any other situation; while the plants and uniones of the northern English coal tracts remind us of the physical characters of the American continent, rivers, and islands.

Periods of Convulsion and Repose.—There is, perhaps, no point of theoretical geology more certainly established than that, in any given small area of the surface of the globe, long periods of ordinary action of natural causes have been several times interrupted by epochs of extraordinary disturbance; that the relation of the level of sea and land has remained for a long time the same, or very gradually changed, and afterwards been altered by internal convulsions. It is also admitted that this law has an extensive, though then less exact application; that the periods of ordinary and crises of extraordinary action were respectively contemporaneous over very large regions of the globe, and even with respect to some of the cases admit of general application. It appears, also, that the nature of the strata deposited differs more or less according to the several successive periods, and that the races of organic remains, in several important cases, are subject to contemporaneous crises. On this evidence, joined to some theoretical considerations, is founded the modern admission of the doctrine of alternating periods of convulsion and repose; a doctrine which was held by ancient philosophers, revived by Leibnitz and Hutton, and illustrated by Cuvier and De

Beaumont. Perhaps this view of the subject was never more clearly expressed than by Leibnitz, whose just sense of the philosophy of geology has been placed in a strong light by Mr. Conybeare. His view is, that the powerful agencies exerted in displacing and altering the solid crust which gradually thickened over the ignited nucleus have many times renewed the face of the young globe by the eruption of concreted igneous rocks from below, and the deposition of stratified rocks by water above; and that the globe was, by these processes, more and more diversified with mountains and valleys, and subjected to various physical conditions; *donec quiescentibus causis, atque æquilibratis, consistentior emergeret rerum status.*

Uniformity of Natural Agencies.—Lyell's pictures of the successive conditions of the globe are all drawn to one scale, from the unvarying standard of its present state. His hypothesis admits local alternations of ordinary and critical action, but denies anything like a general paroxysmal effort of natural agents; nor is there, between the ordinary and critical stages of his processes, any conspicuous difference. The principle of his system is, that the disturbing internal forces exert themselves in irregular succession beneath all the points of the surface of the globe; and that the ordinary chemical and mechanical agencies of nature are thus modified in their intensity, and diversified in their effects, and applied to produce an endless series of destructions and renovations, which, upon the whole, compensate one another continually.

In this system the postulate required is *unlimited duration;* in the other, a varying momentum of natural agencies according to *difference of condition;* the one is a system of continual, the other of intermittent compensation. Nature offers to our view examples of both these cases, and on a large scale: it is therefore very unwise to assume one or the other on account of our notion of its greater probability; we must see which of the systems finds support from the facts of the case. It has been already seen that our *proofs* of the periods of time elapsed are neither clear, satisfactory, nor complete; much of the evidence on this subject is in unknown terms; but estimates derived from probable views of the mechanical composition and organic contents of the strata do not appear to warrant the postulate of unlimited duration.

On the contrary, be the duration of geological periods what they may, it is clear that the earth has successively undergone great physical changes; terrestrial agencies must therefore have operated upon it with a corresponding variation of effect; one of these changes of condition, that of superficial temperature, is not explicable by any of the known periodical inequalities of the solar system, or the irregular fluctuations of surface elements of climate, but seems in harmony with the general theory of internal heat, gradually becoming

less and less sensible as the external crust thickened, and the surface of the globe approached to a state of equilibrium.

Successive Conditions of the Materials of the Crust of the Globe.

The question of the origin or first condition of the elementary ingredients of earthy and metallic substances, if capable of solution, must be referred to another science; but inquiries into the successive conditions of the mineral substances which appear in the crust of the globe is one which, in some shape or other, must be often proposed to a geologist. It is difficult to stop at the recognition of the igneous origin of some rocks, the aqueous production of others; we cannot avoid examining whether any evidence can be found for determining a prior condition of the substances contained in these rocks. Facts of great importance here come before us; we see examples of new rocks produced by heat from aqueous deposits, and sedimentary aggregates of the disintegrated ingredients of volcanic and plutonic masses. The deposition of limestone offers very remarkable variations; and it is impossible to consider the composition of the minerals in crystallized rocks without feeling that the resources of chemistry are or may become capable of advancing us one more step in the analysis of the series of conditions through which the solid ingredients of the globe have passed.

The time is not long gone by when Werner, who, with far less moderation than Dr. Hutton, wished to begin at the beginning, could find thousands of followers in the startling dogma, that all the rocks observed near the surface of the earth, were deposited from one chaotic fluid, which first permitted the crystallization of granitic and other rocks, and afterwards produced the secondary sandstones, shales, and limestones. It is possible that even yet there may be persons who can believe that these secondary sandstones were produced by a chemical decomposition of the ancient ocean; which, to answer all the unreasonable demands upon its powers, must have been endowed with more than the creative energy of a Brahmà, and capable of surmounting every chemical and mechanical impossibility—of crystallizing into sand, condensing into limestone, and subliming into metal!

Leibnitz, and a large portion of modern geologists, also attempt to fix something like a beginning to their system, a point of geological time when the change from a fluid to a solidified surface permitted the development of that series of intermitting igneous and aqueous actions, which has brought the globe by many revolutions to its present state of comparative repose. The followers of Dr. Hutton see no such commencement to their series of terraqueous effects; they find no physical traces of a beginning, nor any change

of operation which should give the prospect of an end of this series of effects proportioned to the time elapsed. Yet, as one hypothesis admits locally, periodically, and repeatedly, what the other supposes to have happened generally and in one succession, there is no necessary disagreement in the interpretation of particular cases. This is not always remembered by those who engage in the controversy concerning the uniformity of natural effects.

Successive Conditions of Certain Substances.—If we trace back the history of the materials of the sedimentary sands and clays now in process of formation at the mouths of rivers, along the sea-coasts, and in other situations, we shall find that these materials are often derived from ancient superficial deposits left by local or extensive floods; examination proves that the materials of these deposits were often obtained by the violent breaking up and attrition of far more ancient previously solidified strata; in several instances it is manifest that these are nothing else than the oceanic accumulations derived from disintegrated primary strata, or of disintegrated pyrogenous rocks.

As an example, we shall quote a well-ascertained series of facts, which leave no doubt of the many changes of condition through which the granular ingredients of modern sedimentary deposits have passed. 1. The Ouse, Trent, and other great rivers connected with the Humber are so filled with the finer parts of the sediments which fall into the sea along the wasting cliffs of Holderness, that their flood waters, when introduced to the lower ground along their banks, deposit a great thickness of valuable soil. The sandy and coarser parts of the sediment are collected in various irregular positions in the Humber and along the coast, and the pebbles remain on the beach, or follow its descent for a small distance into the sea. 2. The diluvial cliffs, which by their destruction afford this rich supply of fertile warp and sterile sand, contain fragments of all the rocks in north-western Yorkshire, that is to say, basalt, limestone of many kinds, cherts, sandstones, fine grained and coarse grained millstone grit, shales, ironstones, and coal; fragments of granite, hypersthene rock, and old slates from Cumbria; all embedded in a vast thickness of sands and clays composed of the same comminuted materials. 3. The millstone grit, fragments of which occur in this diluvial mass, is a compound of felspar, quartz, and mica, with occasional admixtures of other substances. These minerals are easily recognized as *rolled and water-worn masses*, derived from porphyritic granite, gneiss, and other such rocks. The felspar is always perfectly crystallized within, but the external surface is water worn; the mica has lost its angles; and the quartz fragments are only in the state of large grained sand. Plainer proof of mechanical aggregation of ingredients which once composed a crystalline felspathic rock, cannot be

desired. Many such instances are known, and the inference is generally allowed.

Extension of this Inference.—As far as the results of a careful examination of ordinary sandstones can be trusted, there is no reason to refuse to them, as a general rule, the same kind of origin as to coarse millstone grit. Most of them have the same ingredients, though it frequently happens that the felspar is in a state of decomposition. Shales and clays are to sandstones what the fine warp in the water of the Humber is to the sands in its channel. We may then venture, in a moderate spirit of generalization, to assume, that sedimentary sandstones and shales have originated in the mechanical action of water upon the disintegrated granular ingredients of pyrogenous rocks.

Any one who has sufficiently observed the varieties of sandstones and shales on the one hand, and of stratified primary rocks on the other, and considered the nature and amount of the changes produced upon them respectively by heat, or properly weighed the observations and reasonings of MacCulloch, will have no difficulty in admitting the views as to the origin of the latter class of strata advocated in former parts of this essay. We are therefore conducted, apparently by a legitimate process of induction, to the conclusion that all the stratified rocks, limestone and some particular strata excepted, are derived primarily from the decomposing agencies of nature operating upon pyrogenous rocks; and we thus find a natural limit to the series of conditions through which these materials have passed. This conclusion, though perhaps less distinctly stated, is essentially recognized in modern geological systems, and is *felt* to be substantially true, though it still leaves many things to be explained.

Origin of Limestone.—An inquiry as to the origin of the vast masses of stratified limestone is a subject of considerable difficulty. In a great majority of instances the limestone formed at the present day is the result of chemical forces, or of vital forces controlling chemical action; and the same was probably the case in earlier periods. In particular instances calcareous deposits have partially or wholly a mechanical origin; as when a stream brings down the waste of a chalky or oolitic district, and deposits the sediment in a lake; or when the currents of the ocean drift shells and other marine exuviæ and lodge them in the midst of coral reefs. Observers of the growth of coral islands have detected several facts as to the intermixture of decomposed fragmentary and entire calcareous marine exuviæ with coral rock, which seem to render probable the opinion of geologists, that some of the older secondary and transition limestones are in places only magnificent coral reefs.

Perhaps nowhere has the mechanical origin of limestone been

assumed to a greater extent than in the Huttonian system of geology; for it seems to be an essential part of that system, that the stratified limestones are nothing else than triturated shells and other calcareous exuviæ. By those who adopt this view, chalk, the least compacted kind of limestone, is usually taken as an example. It is sometimes difficult to avoid imagining that the powdery magnesian limestone is a recomposed rock, derived from the ruins of magnesian beds of carboniferous limestone. But this cannot be a true account of the matter; for, 1, there ought to be far *less magnesia* in the compound; 2, this is in some instances an atomic combination of carbonate of magnesia and carbonate of lime; 3, this limestone is often really a granularly crystalline rock (like the older magnesiferous beds of mountain limestone), and seldom appears to justify the least suspicion of the mechanical agency of water.

But nothing is more certain than that of all the strata yet discocovered, limestone is exactly that which, by the regularity and continuity of its beds, by the extreme perfection of its organic contents, and by the absence of proofs of mechanical action, gives most completely the notion of a chemical precipitate. It appears sufficiently probable, in several instances, that the quantity of limestone deposited in a given geological period was least towards the shores, and greatest towards the deep sea; exactly the reverse of what happens with the mechanical deposits of sandstone and shale; it may, therefore, be viewed as an oceanic deposit, resulting from a decomposition of sea water, aided in many instances to a wonderful extent by the vital products of zoophytic, echinodermatous, and molluscous animals. According to this view, it is easy to understand the repeated production of limestones of the same mineral character at different periods; nor need we feel surprised that, occasionally, limestones of the same age differ in properties.

However, all these views end at last in one, viz., that the earliest condition which we can assign to the carbonate of lime, is that of extrication from some solution of lime in water, by chemical or vital processes. And here, perhaps, it will be wisdom to pause, for though some have ventured to imagine that the lime might be derived from the decomposition of particular ingredients in primary igneous rocks, and others may suppose that the ocean would more directly obtain this with other ingredients from the oxidized fluid nucleus of the globe, such speculations are hardly within the pale of inductive geology, and involve too many hazardous assumptions to be at present worthy of the notice of other sciences.

General Result.—The general tendency of geological reasoning is to establish the inference, that a large portion of the stratified deposits have been formed from the wasted ingredients of pyrogenous rocks; all the phenomena of volcanoes and ancient igneous eruptions

prove that *locally* stratified deposits are reconvertible to crystalline rocks by the force of heat, and very *generally* alterable in character so as to approximate to the actual products of heat. Lyell puts this to the extreme, and supposes that the calorific energy of the interior of the earth is constantly acting, so as to reconvert sedimentary into crystalline aggregates, *equal quantities* in *equal times*, and thus to maintain a perpetual equilibrium between the liquefying internal and the solidifying external agencies of the globe. This speculation is much too poetical to be examined according to the dry rules of the Baconian philosophy: if the heat expended in this operation be obtained from chemical processes, these must gradually tend towards equilibrium; if from a general internal reservoir of caloric, that reservoir must become less and less prompt in supplying the incessant demand: either of these effects operating through *indefinite time* must cause the gradual refrigeration of the surface of the globe, a consequence not favourable to the hypothesis of the uniformity and continual compensation of the effects of internal and external terrestrial agencies.

APPENDIX.

TABLES AND CALCULATIONS.

PHYSICAL RELATIONS OF THE GLOBE AS A PART OF THE SOLAR SYSTEM.

THE EARTH AND THE SUN.

Figure of the Earth, a spheroid of revolution, with diameters as 298 : 299.

Equatorial diameter...........792·5648 miles.
Polar diameter ....7899·170
} Difference, commonly called the compression .... = 26·478 miles.

Mean distance from the Sun, 95,000,000 miles.

Obliquity of Ecliptic, 23° 28′.

						d.
Time in which the Sun returns to the equinox, called the Equinoctial, or Tropical, or Civil Year............	36^{d}	5^{h}	48^{m}	51·6	or	365·242364
Annual precession of the equinox, ∠ 50″·1 = in time............	0	0	20	19·9		0·014119
Sidereal Year............	365	6	9	11·5		365·256383
Annual precession of the apogee, ∠ 11″·8 in time............	0	0	4	47·3	or	0·003325
Anomalistic Year............	365	6	13	58·8		365·259780

THE EARTH AND THE MOON.

Mean distance of the Moon from the Earth, 59·9643 equatorial radii of the Earth:

An equatorial radius = 3962·824 miles. Hence, distance of the Moon's centre from that of the Earth = 237628 miles nearly.

Diameter of the Moon............	2160 miles.
The mass of the Earth being............	1·0000000 —
That of the Moon is............	0·0125172 —
Mean sidereal revolution of the Moon............	27·321661418 days.
Mean synodical revolution of the Moon............	29·530588715 —
Eccentricity of orbit............	0·054844200
Mean inclination of orbit............	5° 8′ 47″·9.

THE EARTH AND THE OTHER PLANETS.

PLANETS' NAMES.	Mean Distance from the Sun.	Mean Sidereal Period in Mean Days.	Eccentricity in Parts of the Mean Distance.	Inclination of the Orbit to the Ecliptic.	Mass in Billionths of the Sun's.	Equatorial Diameter, the Sun's being 111·454.
Mercury.....	0·387	87·969	0·2055	7° 0′99″·1	493628	0·398
Venus........	0·723	224·700	0·0068	3 23 28·5	2463836	0·975
Earth........	1·000	365·256	0·0167	——	2817409	1·000
Mars........	1·523	686·979	0·0933	1 51 6·2	392735	0·517
Vesta........	2·367	1325·743	0·0891	7 8 9·0	——	——
Juno.........	2·669	1592·660	0·2578	13 4 9·7	——	——
Ceres.........	2·767	1681·393	0·0784	10 37 26·2	——	——
Pallas........	2·772	1686·538	0·2416	34 34 55·0	——	——
Jupiter.......	5·202	4332·584	0·0481	1 18 51·3	953570222	10·860
Saturn.......	9·538	10759·219	0·0561	2 29 35·7	284738000	9·987
Uranus......	19·182	30686·820	0·0466	0 46 21·4	55809812	4.332

(*From Sir John Herschel's Astronomy.*)

TEMPERATURE OF THE GLOBE.

Land.—The mean temperatures near the level of the sea vary nearly as the cosines of latitude. Thus, if the equatorial mean temperature = 81°·5 Fahr., the mean temperature for any latitude = 81°·5 cos. lat. This is found to apply pretty well until we arrive near the polar circle, when several anomalies occur, which seem to indicate at least two centres of maximum cold, one in America, one in Asia. But the mean temperature of particular places, in any circle of latitude, varies greatly from the mean of the latitude. Dove's Maps of Isothermal Lines show all the variations in a clear and accurate manner.

Water.—The oceanic temperature is not subject to the same extremes as that of the land: it does not diminish so fast toward the poles, and consequently permits the existence of marine animals in latitudes which are fatal to nearly all terrestrial beings.

Fresh water is heaviest at about 38°·75 Fahr., growing lighter both by heating and cooling; and consequently, in latitudes which permit of this degree of cold at the surface during the winter, there will then be a falling of cold water, and a rising of warm water, so as to counteract materially the rigour of the season. In latitudes where it is only in summer that the surface water can be heated to 38°·75, the warmed water will then sink from the surface, which at other times may freeze, and experience extreme cold, while the bottom is warm.

This does not apply to the ocean; for it is found that salt water goes on increasing in density as it cools, even to some degrees below freezing. The variations of the temperature of the sea, in relation to depth from the surface, are not yet sufficiently known. It appears, however, that the

reduction of temperature in the deep parts of the tropical seas is very considerable.

In lat. 3° 26′ S.	surface 73°	1000 fath.	42°	Wauchope.
20 30 N.	83	1000	45·5	Sabine.
9 21 N.	83	250	77	Kotzebue.
0 0	83	300	55	

Mean reduction of temperature in tropical latitudes ...... 1° F. in 25 fathoms.

In lat. 36° 9′ N.	surface 71°·9	100 fath.	52°·8	Kotzebue.
30 39 S.	67	300	44	
44 17 S.	54·9	196	38·8	

Mean reduction of temperature in lat. 37° 2′ .... 1° in 28 fathoms.

In lat. 79° 4′ N.	surface 29°	13 fath.	31°	Scoresby.
		37	33·8	
		57	34·5	
		100	36·0	
		400	36	
		730	37	
76° 16′ N.	28·8	50	31·8	Ditto.
		123	33·8	
		233	33·3	
78° 2′	32	761	38	
60° 44′		100	30	Ross.
		200	29	
		400	28	
		600	25	
67°	4400 par. feet		2°·6 R.	Irving.
78°	660 ditto		0 ·4	

Atmosphere.—The decrease of temperature, as we ascend from the level of the sea, is subject to so many causes of fluctuation and local diversity, that it has been found very difficult to come to any general conclusion. In equatorial regions, according to Humboldt, there is a diminution of temperature = 1° Reaum. for 121 toises of ascent: at St. Bernard, 1° R. for 123½ toises = 1° Fahr. for 352 feet English. At Ventoux, near Avignon, 1° R. corresponds to 80 toises in summer, and to 100 in winter: on the Righi, 1° R. for 97 toises. In the north of England, Nixon's experience, on mountains of 1,000 to 2,000 and 3,000 feet, gives 1° F. Dr. Dalton allows 1° F. to 100 yards elevation. Generally it is found that the temperatures diminish more rapidly from the lowest stations.

The above statements apply to the air *near the ground*, where it is influenced by the heating surface of the earth. We do not know what is the law of diminution of the heat in the air directly upwards from the ground. Over England, indeed, the Balloon Experiments, recorded by Mr. Welsh, give results not greatly differing from the general estimate of Humboldt.

Springs.—The unfailing springs which gush out from fissures of rock, bring with them the temperature of their shallow subterranean channels; and this temperature is generally found to be constant, and in cold regions a little higher than the mean temperature of the air. This was first

noticed by Dalton, and has since been made the subject of extended inquiry by Prof. Küpffer, from whose researches it appears, that the difference of shallow subterranean mean temperature from that of the air above the surface of the ground follows a certain law, depending on the latitude and on local influences. Near the equator, the ground, at 25 metres depth, appears to have a temperature 2° R. *below* the mean temperature of the air; whilst in Lapland it is 2° *above* it. This appears to be a strong corroborative argument for the internal temperature of the earth depending on a cause distinct from solar influence.*

Subterranean Heat.—The fluctuations of superficial temperature diminish as we descend into the earth, so that at last we arrive at a point where, through the whole year, there is no change, and consequently below which the variation of solar influence is insensible. This depth is called the *invariable stratum.* From the observations in the caves at Paris, it is inferred to be nearly 30 metres, or 100 feet from the surface. Below this depth, any differences in the temperature of the earth must be ascribed to internal terrestrial peculiarities. It is found that below the invariable stratum the temperature of any point is wholly uninfluenced by seasons, and is constant; that the temperature augments regularly in proportion to the depth, at a rate, upon the average, of 1° F. for 15 or 20 English yards. It is clear, therefore, that there is a proper source of heat within the earth.

The warm and hot springs, which issue from great depths, yield another and very satisfactory proof of the existence of great heat within the earth. Some of these are closely connected with existing volcanoes, others with lines of convulsion, which open a communication to the deep parts of the earth. It is clearly to this communication that the heat is owing, and not to any local chemical actions along the channels; for the chemical composition of the waters is by no means uniform, and, perhaps generally, hot waters are as pure as others. In some places hot and cold springs rise within a few feet of each other.

Temperature of the	Great Geyser	209°	Sir G. Mackenzie.
—	La Trinchera, 3 leagues from Valencia	194·5	Humboldt.
—	Carlsbad	165	Ure's Chemical Dictionary.
—	Aix-la-Chapelle	143	
—	Bath	116	
—	Buxton	82	
—	Hotwells	74	
—	Matlock	68	

THERMOMETRICAL SCALES.

The freezing point of water is marked 32° on Fahrenheit's thermometer; but on Reaumur's and Celsius's or the centigrade, it is marked 0°. The boiling point of pure water (when the barometer is at 30·0) is marked 212° on Fahrenheit's, 80° on Reaumur's, 100° on the centigrade. Hence

* Forbes, in Report to the British Association, 1832.

the relative *values* of the thermometrical unit or degree are, on Fahrenheit, 1°; on the centigrade, 1°·8; on Reaumur 2°·25. Hence the following rules:—

1. To reduce to Fahrenheit the observations on the other scales:—

 Multiply the number on Reaumur's by 2¼, and add 32°.
 Multiply the number on the centigrade by 1·8, and add 32°.

2. To reduce to the centigrade scale observations on the others:—

 Multiply the number on Reaumur by 1¼.
 Diminish the number on Fahrenheit by 32°;
 And multiply the remainder by 0·555+,
 Or divide it by ....1·8.

It is much to be recommended that philosophers should adopt one uniform scale.

Value of English Measures in French Metres.		Value of French Measures in English Inches.	
English INCH	0·0254	French Millimètre	0·03937
— Foot	0·3048	— Centimètre	0·39371
— Yard	0·9144	— Decimètre	3·93708
— Fathom	1·8287	— METRE	39·37079

THE BAROMETER.

A little experience in moderately elevated regions of stratified rocks will convince the geologist who values the connection of the physical sciences, or desires to give the utmost accuracy to his results, that it is wrong to neglect the use of the portable barometer. The objections usually urged against the Englefield barometer are of little importance, if the construction of the instrument has been properly attended to. Heights of ground, thicknesses of rocks, otherwise often unascertainable, extent of dislocation, and many other useful data may be thus quickly obtained, *at the time when they are most wanted*, by the geologist. No apparatus is needed for the support of the instrument; and, provided the observer be steady of hand and sure of eye, his observations can hardly fail to be correct. The observations are, 1. The height of the barometer, in inches, tenths, hundredths, and thousandths, at each station; 2. The degree of the thermometer *attached* to the instrument at each station; 3. The degree of this or another thermometer *detached* from the instrument, and exposed to the air in the shade, at each station.

To calculate with tolerable accuracy the difference of level corresponding to any two sets of observations, the following easy and brief processes will be sufficient, without special tables or logarithms, for altitudes under 4,000 feet, and in the latitudes of Great Britain. The geologist is recommended to copy them into his *field note-book*.

1. Having written down the observations as they were made, take the mean and difference of the barometer, the difference of the attached thermometer, and the sum of the detached thermometer.

2. Correct the barometer difference for relative capacity of tube and cistern. This correction is always additive, and its value is marked on the barometer.
   Mr. Nixon has explained a method of construction which removes the necessity of this correction in his portable barometers.

3. Correct for difference of att. therm., by multiplying that difference by $\frac{1}{10000}$th of the mean barometric pressure. The product must be subtracted from the barometric difference (2.) when the upper station is colder; added to it when warmer.

4. Correct for the temperature of the air above 0° Fahr. by the following process:—Consider the sum of the det. therm. as thousandths; add to it the integer 1·000; multiply together this sum, the corrected barometric difference (3.), and the constant number 24900; divide the product by the mean barometric pressure (1.). The quotient is the height in English feet, nearly.

Example of the whole Process.

(1.)	Lower station, Bar. Press....	30·040	Att. Ther.	72·5	Det. Ther....	72·0
	Upper station, —	26·575	—	63·5	—	62·6
	Mean..................	28·307	Diff.........	9	Sum..........	134·6
	Difference...........	3·465				

(2.) In this instrument the capacity is allowed for by the construction.

(3.) $9 \times \cdot 00283 = \cdot 0254$ and $3\cdot 4650 - 0\cdot 254 = 3\cdot 4396$.

(4.) Sum of Det. Therm. $+ 1\cdot 000 = 1\cdot 146 \; \dfrac{1\cdot 1346 \times 3\cdot 4396 \times 24900}{28\cdot 307} = 3433\cdot 7$ feet.

In lat. 54°, the height by Oltmann's Tables in De la Beche's Manual, is 3432·3; height by Nixon's Tables (Phil. Mag.), 3435·9.

The fluctuations of the barometer are not necessarily productive of error in the use of the instrument. It is not requisite to have more than one barometer, provided the observer returns again, in the course of the day, to the point which he has chosen for his reference station, or verifies his results by including amongst his measures some point whose height, compared to that reference station, is known, or in any other way can know the hourly rate of the rising or falling of the barometer.

For Example, Sept. 22, 1832:—

	Bar.	Time.	Att. and Det. Therm.	Correction for Temp.	Corrected Pressures.
Inn at Hawes	29·878	9^h 40^m	60°	·000	29·878
Gale....................	29·800	11 0	58	+ ·006	29·806
Summit of a hill.....	28·735	12 0	55	+ ·015	28·750
Inn at Hawes........	29·850	2 0	64	— ·012	29·838

Hence it is seen, that in 4h. 20m. the barometer fell ·040; and by applying a correction, in this proportion, to all the observations,

$$\text{we have} \left\{ \begin{array}{l} 29\cdot 878 + \cdot 000 = 29\cdot 878 \\ 29\cdot 806 + \cdot 012 = 29\cdot 818 \\ 28\cdot 750 + \cdot 022 = 28\cdot 772 \\ 29\cdot 838 + \cdot 040 = 29\cdot 878 \end{array} \right\} \text{true relative pressures.}$$

THE ANEROID.

Much of the calculation necessary to obtain differences of vertical height, from the measures of the mercurial column in the barometer, is avoided by the use of the newly invented instrument called the aneroid, in which metal springs balance the pressure of the air on a plate, and as liquid* is used. These instruments, if carefully made, are of admirable efficiency *within the limits of altitude above the sea level*, for which they have been properly adjusted. I have found several fail utterly at heights of 2,000 to 3,000 feet, but have used others with the greatest satisfaction for elevations not exceeding 1,000 feet. There is a small correction *for temperature of instrument*, required for extreme precision, but this is of little consequence in geological inquiries. The temperature of air at both stations should be noted. The computations are reduced to those in article (4) for the common barometer.

CLINOMETER.

In ascertaining generally the direction and angle of the dip, and direction of the horizontal line or strike of the stratified rocks, nothing is more convenient than the pocket clinometer, fitted with a compass-needle as usually sold in London. Mr. Pratt has lately (*Philosophical Magazine*) proposed an improvement in it. For accurate determination of the strike of beds, direction of joints, and bearings of objects on the surface (which the geologist will often need) better instruments than those commonly in use are necessary. Gambey's and other clinometrical compasses are (if rightly used) very satisfactory. A very ingenious instrument applicable to geological surveys, as well as ordinary clinometrical uses, is manufactured by Mr. Dunn of Edinburgh. Capt. Kater's or any other good surveying-compass, may often be found to give curious results among certain primary rocks, along dikes of basalt, &c. The variation of the needle (now from 24° to 26° west in the north of England) being marked on the circle, the geologist may record his observations in true bearings.

Unprovided with a clinometer, a jointed rule will suffice to those acquainted with trigonometry; and a faithful drawing will often be as good as any measure. When it happens (as in a cliff) that there are two or more lines of section exposed, neither of which passes along the line of dip, or line of strike, the amount of dip, and direction of dip and strike, can be calculated trigonometrically from the observed dips and directions of the rocks exposed in the sections. (See a paper on this subject in the *Transactions of the Royal Society of Edinburgh*, by M. Necker.)

The use of the clinometer is soon learned, and questions of the highest importance in the very first stages of physical geology can only be solved by frequent and exact observation with this instrument. It is at present uncertain whether the direction of great axes of dislocation has been influenced by a previous jointed structure of the rocks; and what is the relation of faults, dikes, veins, and cleavage to this structure and those axes; for the evidence yet collected on this subject is by no means decisive. Several problems are here presented to the observer. 1. The degree of symmetry of the jointed structure as indicated by the predominance of

* Hence the name, α, privative, and νηρος, liquid.

particular directions in it. 2. The geometrical relation of these divisional planes to faults, veins, &c., and to the centres or axes of great subterranean movements. 3. The age of the joints as compared to any neighbouring faults, veins, or axes of movement. 4. Similar inquiries as to cleavage.

The following remarks may be of use to persons who are anxious to furnish correct data for the solution of these and other questions:—

The strike and dip of the strata are always most certainly exhibited among thin bedded rocks, especially where layers of different nature alternate: thick bedded sandstones are likely to mislead a novice by their oblique lamination; thick limestone beds have often nodular surfaces; but shales, thin bedded limestones, and flagstones, generally yield consistent measures of dip and strike.

On a large scale the dip and strike may be calculated from good barometrical measures of the relative elevation above the sea of three points at known distances, on any one plane of stratification. In reasoning on the relation of axes of elevation to joints, faults, and mineral veins, general results thus obtained are of great value.

The strike can almost always be taken with more accuracy than the dip. The dip being at right angles to the strike is easily measured, if care be taken that during the process the plane of the clinometer is vertical. The unevenness of the surface of beds may be remedied by employing a clinometer with long radius; in using Gambey's or any other clinometric compass-box, a long straight rod, or the edge of a sketch-book will be of service.

Divisional Planes are generally most symmetrical in those rocks where the stratification is most regularly parallel, as in the argillaceous plates of Aldstone Moor, the thin limestones of Craven and Derbyshire, and the thin beds of coarse slate at Aberystwyth. In examining the strike and dip of cracks, joints, and fissures, it is requisite to try more than one example of any set supposed to be parallel, in order to know whether they are so; or what are the limits of error. In some situations two sets of joints appear, in others (as in the oolitic rocks and carboniferous formations of Yorkshire), a diagonal set sometimes occurs. In order to state a general law of the direction of the strike or dip of the joints in any country, a great number of instances, collected at distant points having nearly the same relation to an axis of elevation, should be carefully discussed in a tabular form to obtain the mean result. To learn the nature of the geometrical relation of joints, faults, veins, &c., to centres and axes of subterranean movement, observations made *far* from such situations should be compared with others made *near* to them. It is very important to ascertain whether veins, faults, &c., *change their course*, and in what manner, at or near the centres or axes of movement;—do faults converge towards a centre of elevation, as Mr. Hopkins has observed in Nottinghamshire; do mineral veins cross at right angles an anticlinal axis or master fault, as I have found to be the case in Yorkshire? In every instance the exact strike and dip of the strata in the same situation must be recorded; for where the dip of the strata is considerable, observations of the planes of joints, faults, &c., must in most cases be submitted to calculation before their true relations to the axis of movement can be known. The object of the calculation is to ascertain what *would* be the strike and dip of any joint-plane, if the strata were *restored* to their original level position.

EXAMPLE NOT REQUIRING CALCULATION.

Brecon, Sept., 1836, *in old red sandstone.*

Strike of Strata	N.E.	Dip S.E.	(0 to 3°).
— Joints A. N. 45° 46° 47° E.	E.	— N.W.	(90° 87° 81°).
— Joints B. N. 15° W.		—	nearly vertical.
— Joints C. N. 10° E.		—	nearly vertical.

EXAMPLE REQUIRING CALCULATION.

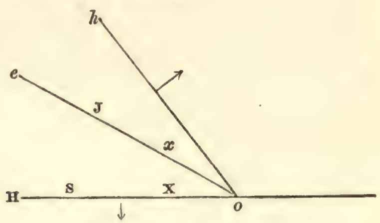
North side of the anticlinal axis of Corn y Vaen, Sept., 1836, *in Ludlow Rocks.*
(Taken with Sir R. Murchison.)

Strike of Strata	N. 41° E.	Dip N. 49° W.	(37½°).
— Joints A.	N. 44° W.	— S. 46° W.	(87°).
— Joints B.	N. 62° E.	— S. 28° E.	(63°).

If the strata could be replaced in their original nearly level position, the following would be the measures taken on the same planes:—

Strike of beds	(level)	Dip	(level.)
— A.	N. 46° 51′ W.	— S. 43° 9′ W.	(84° 34).
— B.	N. 59° 50′ E.	— N. 30° 10′ W.	(81° 35).

The mode of obtaining these results may be understood by attending to the following processes with logarithms:—



Let Δ be the dip of the plane of stratification S;
δ that of the plane of any joint J, *outwards* from
e, the common edge of these planes; a perpendicular dropped from which will thus fall within
θ, the angle included between the horizontal lines or strikes of these planes; o H, and $o\ h$.

1. Cosine Δ + cot θ (or complement of θ to 180°) = log of nat. number n, which if θ be greater than 90° is +, but if less it is —.
2. Sin Δ + cot δ + cosec θ (or complement of θ to 180°) = log of nat. number p, which agreeably to the position prescribed for δ is always —.

The sum or difference of p and n = nat. tang. of an angle which is + or — according to the sign of the sum or difference: and being combined with + 90° gives the superficial angle X on the plane S, included between the common edge e and the strike of S.

In the same manner x, the corresponding angle on the plane J, may be found.

(The *bearing* by compass of the edge e, when S is supposed to be replaced in its level position, is found by substituting the angle X for the angle θ, in combination with the strike of S.)

Then cot δ + sec x (or the complement of x to 180°) = cot (w) of the dip of the plane J at right angles to the edge e.

cot Δ + sec X (or its complement to 180°) = cot (W), the corresponding dip of the plane S.

If either X or x exceed 90°, the dip of the plane which includes it is —.

The sum or difference of W and w = dip of the plane J on the plane S, supposed to be replaced in its horizontal position.

For those geologists who are unaccustomed to calculation, and yet are desirous of using and rendering useful to others observations of joints,—which, if made among inclined strata, are of *no value in reasoning* till they are reduced,—a well-constructed model would be very serviceable;* in many instances, especially among the older argillaceous rocks, the edge (e) of the joint on the plane of stratification can be seen, and the plane angles X and x, and the dihedral angle of e measured by the clinometer; no calculation is then needed. Finally, it must ever be borne in mind, that in the philosophical study of jointed structures, accurate and complete measures are of the highest importance, and others are something worse than useless.

The strike and dip of the cleavage in slaty rocks is a very interesting and easy subject of inquiry; and if conjoined with exact determinations of the planes of stratification, divisional joints, faults, quartzose and mineral veins, results of great theoretical value may be deduced. It should be carefully observed whether the cleavage planes vary in their inclination from the vertical according to the different beds of slate, (for the slate rocks *are* perfectly bedded,) and the other coarse schistoze rocks which accompany or enclose them. It is very desirable to know if there are many exceptions to the law, stated by Sedgwick, that the strike of cleavage is generally coincident with that of the stratification, and under what circumstances these occur. If the planes of strata change their inclination, does the inclination of the cleavage vary in any assignable ratio? If the slate beds are contorted, do the cleavage planes retain their bearing and dip across the contortions (as at Aberystwith)?

What is the effect of faults, quartz veins, &c., upon the perfection and symmetry of the cleavage? What is the relation of the numerous joints in slaty rocks to the plane of cleavage, the plane of stratification, and the planes of the veins and faults? The answers to these questions which I have obtained by measurements in the slaty regions of Wales and Yorkshire, appear to contain important evidence with reference to the geological date and influential circumstances of the production of slaty cleavage and other symmetrical structures. To assist in guiding inquiries on this subject into a right channel, I propose the following general formula of observation:

Date ( ) : *Locality* ( ) :

Description of the rocks: Marks of stratification: Notices of contortion of the beds: Qualities of different beds of slate: Occurrence of joints, veins, &c.

Strata	strike	N. 44° E.	Dip	N. 46° W.	(45°).
Cleavage	—	N. 40° E.	—	N. 50° W.	(87½°).
Joint *a*	—	N. 86° W.	—	N. 4° E.	(76°).
— *b*	—	N.	—	W.	(72°).
— *c*	—	N. 45° W.	—	vertical.	
— *d*	—	Horizontal Tables.			
— *e*	—	N. 40° W.	—	N. 50° E.	(35°).

* I have employed a simple instrument of this kind which gives by inspection the reduced value of direction and dip in every possible case of the intersection of the plane of stratification by joints, cleavage faults, mineral veins, &c. It is constructed for the general use of Miners and Geologists, and may be obtained, at a moderate price, of Messrs. Longman and Co.

ZONES OF LIFE IN THE SEA.

Professor E. Forbes, now unfortunately lost to science, explored the Ægean Sea, and divided it into eight zones of depth, whose inhabitants he examined and compared.

The following table exhibits the main results, and will suggest to geologists many interesting considerations regarding the depths of sea at which the several shell deposits took place :—

Sea Bottom.	Zone.	Extreme Depth of Zone in Fathoms.	Characteristic Plants and Animals.	
			Animals.	Plants.
Rocky, sandy, with conglomerates forming.	I.	2	Littorina cærulescens, Fasciolaria tarentina, Cardium edule.	Padina pavonia.
Muddy, sandy, or rocky.	II.	10	Cerithium vulgatum, Lucina lactea, Holothuriæ.	Caulerpa zostera.
Bluish mud or sand.	III.	20	Aplysiæ, Cardium papillosum.	
Gravelly and weedy; in estuaries muddy.	IV.	35	Ascidiæ, Nucula emarginata, Cellaria ceramoides.	Dictyomenia volubilis. Codium bursa.
Nulliporous—shelly.	V.	55	Cardita aculeata, Nucula striata, Pecten opercularis, Myriapora truncata.	Rityphlœa tinctoria.
Nulliporous — rarely gravelly.	VI.	79	Venus ovata, Turbo sanguineus, Pleurotoma maravignæ, Cidaris hystrix.	Nullipora.
Nulliporous — rarely yellow mud.	VII.	105	Brachiopoda, Rissoa reticulata, Pecten similis, Echinus monilis.	Nullipora.
Yellow mud, with remains of Pteropoda and Foraminifera.	VIII.	230	Dentalium quinquanqulare, Kellia abyssicola, Ligula profundissima, Pecten Hoskynsi, Ophiura abyssicola, Idmonea, Alecto.	No plants.
Probably no animal life in this sea at a greater depth than 300 fathoms.				

The same author presents a valuable summary of the distribution of shells in the several zones of depth:—

Zones of Depth.	Multivalves.	Patelliform.	Tubular.	Holostomatous.	Siphonostomatous.	Pteropoda and Enichobranchiata.	Brachiopoda.	Lamellibranchiata.	Total.
I.	3	11	4	50	40	1	0	38	147
II.	2	3	4	40	27	0	0	53	129
III.	0	2	2	40	30	0	0	52	124
IV.	2	3	2	44	41	0	2	68	142
V.	2	5	1	35	36	0	4	58	141
VI.	1	6	1	28	30	0	5	48	119
VII.	1	6	2	17	16	3	7	34	85
VIII.	0	1	2	15	5	12	3	28	66
Total Species......	7	20	6	115	104	12	8	135	
Total Occurrences in Zones.........	11	37	18	269	225	16	21	379	
Ratio of Number of Occurrences to Number of Species.......	1·6	1·8	3·0	2·3	2·1	1·3	2·6	2·8	

CONSTITUENT INGREDIENTS OF ROCKS.

It has already been stated that notwithstanding the immense variety of rocks which solicit the attention of a geologist, a correct knowledge of only a limited number of mineral substances is sufficient to enable him to trace and recognize these rocks, and describe them satisfactorily to others. The following short list includes those that appear most essential for this purpose. It is hardly necessary to observe that the student will do well to endeavour to familiarize himself with these minerals, by considering the variation of their appearance and modes of combination with one another, and examining them in a crystallized, amorphous, and decomposed state. For this end he should often contemplate arranged cabinets of minerals, and collect fragments of compound rocks. A little practice will give him a knowledge of their characteristic forms, hardness, specific gravity, and ordinary optical characters.

Quartz.
Orthoclase Felspar.
Mica.
Hornblende.
Actinolite.
Augite.
Hypersthene.
Diallage.

Olivine.
Analcime.
Schorl.
Chiastolite.
Chlorite.
Green earth.
Talc.
Steatite.

Garnet.
Carbonate of Lime.
Carbonate of Magnesia.
Sulphate of lime.
Muriate of soda.
Bitumen.
Iron, Oxide of
——, Sulphuret of

The hardness of minerals is expressed in the following convenient scale, of early recognizable species :—

1. Talc.	4. Fluor spar.	7. Quartz.
2. Gypsum.	5. Apatite.	8. Topaz.
3. Calcareous spar.	6. Felspar.	9. Corundum.
	10. Diamond.	

The specific gravity of a mineral is expressed by comparison with water. Thus, 2·5 in the case of felspar, shows that its specific gravity is twice and half that of water.

Those geologists who have occasion to examine into the history of mineral veins, must, in addition, make themselves acquainted with metals, alloys of metals, and combinations of metal with sulphur, selenium, carbon, oxygen, and acids.

To assist in the acquisition of the requisite knowledge of these minerals, the following statement of some of the modes of their occurrence in a considerable number of rocks many be found useful.

The appearance of minerals in rocks is often much different from that which they bear in detached specimens.

QUARTZ. Crystallized in double six-sided pyramids in the substance of granitic, porphyritic, and other igneous rocks; in six-sided prisms terminated by six-sided pyramids in mineral veins and in cavities in granite; compact in veins; nodular in amygdaloidal traps; rolled masses in old red conglomerate, millstone grit,and grauwacke; worn grains in sandstones, clays, certain quartz rocks, and coarse clay slates. Specific Gravity 2 6. Hardness 6.

ORTHOCLASE FELSPAR. Primary rhomboidal crystals in granite, porphyry, trachyte; composite and modified crystals in cavities of granite, and veins; disturbed crystals in gneiss; rolled crystals in conglomerate; decomposed to porcelain clay in some granites and sandstones. Colour, red, white, greenish. Specific Gravity 2·5-2·7. Hardness 6. (There are other species of Felspar.)

MICA. Crystallized in brilliant elastic laminæ, composing hexagonal plates in granite, porphyry, lava, and primary limestone; disturbed crystals in gneiss and mica schist; fragmentary scales in sandstone, sand, shale, and clay. Colour various. Specific Gravity 2·6. Hardness 2·5-7.

HORNBLENDE. Crystallized in rhombic prisms with felspar, &c., in syenite, greenstone, basalt, also in hornblende slate. Colour black or green. Specific Gravity 3·2 to 3·4. Hardness 5·5.

ACTINOLITE. Crystallized in long slender, often radiating prisms in hornblende slate, in veins. Colour green. Spec. Grav. 3·0 to 3·3. Hardness 6. (A variety of Hornblende.)

AUGITE or PYROXENE. Crystallized in rhombic prisms with felspar in augitic greenstone, augitic basalt, melaphyre, lava; also in primary limestone. Colour black, green. Specific Gravity 3·3. Hardness 6.

HYPERSTHENE. Crystallized with felspar in hypersthene rock, hypersthenic syenite, hypersthenic granite, hypersthenic greenstone. Colour black, green, gray. Specific Gravity 3·4. Hardness 6.

DIALLAGE. Crystallized with felspar in gabbro or diallage rock; obscurely crystallized in serpentine; fine grained in serpentine. Colour green. Specific Gravity 3·1. Hardness 4·5.

OLIVINE. Crystallized and granular in lava, basaltic and other igneous rocks. Colour greenish. Specific Gravity 3·2. Hardness 6.

EPIDOTE. Crystallized in slender prisms, or granular in syenitic and other igneous rocks. Colour usually pale green. Specific Gravity 3·4. Hardness 6·5.

ANALCIME. Crystallized in cuboidal forms in lava, basaltic, and other igneous rocks. Colour pale. Specific Gravity 2·1-2·2. Hardness 5·5.

ASBESTOS. Fibrous varieties of hornblende, augite, and other minerals, rather than a peculiar species, receive this name. The fibres run across veins of the substance.

SCHORL. Crystallized in striated prisms with quartz in the "cockle" rock of Cornwall. Colour black. Specific Gravity 3·0 to 3·3. Hardness 7.

CHIASTOLITE. Crystallized in four-sided prisms, (hollow in centre,) in the clay slate of Cumberland, Spain, and Ireland. Colour pale or white. Specific Gravity 3·0. Hardness 6.

CHLORITE. Crystallized in pearly non-elastic laminæ, composing hexagonal plates in veins, and granite; amorphous in chloritic mica schists, and clay slates. Colour usually green. Specific Gravity 2·8. Hardness 1·0-1·5.

GREEN EARTH. Amorphous, pulverulent, or compact, in amygdaloidal porphyries, basalts, and wackes.

TALC. Crystallized in non-elastic laminæ, composing soft masses in some granites. Amorphous and earthy, in veins, talcose schist, and primary limestone. Colour pale. Specific Gravity 2·77. Hardness 1.

STEATITE. Amorphous in serpentine, granite, clay slate, and veins.

GARNET. Crystallized in rhomboidal dodecahedrons, in granite, gneiss, mica schist, clay slate, primary limestone; near trap dikes; in veins. Colour red, and various. Specific Gravity 3·7 to 4·0. Hardness 7, (brittle.)

CARBONATE of LIME. Crystallized in veins, cavities of calcareous rocks, shells, primary limestone, and stalactites; amorphous in limestone rocks; concretionary in oolites; fibrous in certain limestones and shells; nodular in amygdaloidal traps; laminar in shells and corals; pulverulent in rock marls, chalk, &c. Specific Gravity 2·4 to 2·7. Hardness 3.

CARBONATE of MAGNESIA. Crystallized in veins; amorphous in certain clays; combined with carbonate of lime in dolomite, magnesian limestone. Specific Gravity about 3·0. Hardness about 4·0.

SULPHATE of LIME. Crystallized (selenite) in clays; fibrous, compact, pulverulent (gypsum) in clays, &c. Specific Gravity 2·3. Hardness 2·0.

MURIATE of SODA. Crystallized in rock salt; invisibly disseminated in most rocks; in lava. Specific Gravity 2·1. Hardness 2·0.

BITUMEN. Concrete or liquid in certain limestone rocks, shells, and veins; disseminated invisibly through the mass of many shales and limestones.

OXIDE of IRON. Crystallized in octohedral and other forms, lava, syenite, hypersthene rock, and veins; minutely disseminated in sandstones, clays, ironstones, ochre, &c. &c. Specific Gravity 4·6 to 5·2. Hardness 5·5.

SULPHURET of IRON. Crystallized in clay slates, primary limestones, near trap dikes, in chalk, clays, argillaceous limestones; in artificial products, both of aqueous and igneous origin. Specific Gravity 4·7 to 5·0. Hardness 6·0 to 6·5.

GLOSSARY.

GEOLOGISTS employ as if they were English, or at least *anglicized*, many words derived from Greek, Latin, Italian, French, German, and Swedish, such as pyrogenous, stratified, brecciated, terrain, grauwacké (greywacké), trap. Other words, previously accepted in English composition, are employed by geology in a sense more or less technical or limited. In the glossary which follows, a considerable number of such terms is included, though often borrowed from physical, chemical, zoological, and botanical nomenclature. Another class of words, familiarly employed in classification, retaining more or less accurately the Greek or Latin form, and amounting to many thousands, is noticed in this glossary, but only so far as they indicate classes, orders, and remarkable groups of mineral and organic bodies. To pass beyond this limit, would be to write several additional treatises.

In perusing any glossary, having such objects, the reader may be reminded that in adapting Greek words to the English ear and eye, the practice even of scholars has not always been uniform. A frequent source of embarrassment is found in the pronunciation of words containing the English *g*, for the Greek *γ*. The originally hard sound is *usually* softened in our language before the vowels *e*, *i*, *y*. Thus, Geology, Augite, Gyration, usually have the *g* soft in English and French: not so in the German. Before *a*, *o*, and *u*, the same letter is usually hard. By common consent the English *c* represents the Greek *κ*, and it seems desirable that the sound should be settled on the same plan as that most frequently adopted in the case of *g* and *γ*. We should then have the sound of Ceratite, not Keratite; Cephalopod, not Kephalopod; Cyathocrinus, not Kyathocrinus. If Cainozoic (*καινος*) and Poikilite (*ποικιλος*) were pronounced as Cænozoic and Pœcilite, we should have a tolerably uniform pronunciation. The Greek letter *χ* being always anglicized by *ch*, and then pronounced hard, as in Suchosaurus, Cheirotherium, causes little difficulty. The word Schist is a singular exception, it being derived from *σχιζω*, and yet pronounced "shist."

So many new terms are required in Palæontology, that perhaps a remark on orthography may not be unsuitable. In deriving terms from Greek words which originally contain such syllables as *και*, *δει*, *ποι*, we may be allowed to retain the diphthongal form, at least when it is essential to the meaning. Thus Deinosauria, not Dinosauria, (containing *δεινος*, terrible, not *δινη*, a vortex).

Uniformity in spelling is gradually identifying German, French, and English terms—though we still find Ictyosaurus and Icthyosaurus for Ichthyosaurus—Dysaster for Disaster—Didelphis for Didelphys.

The terminations *lites*, *ites*, implying stony or fossil, once so common in palæontology, and still retained in several instances, especially among Cephalopoda and Crinoidea, will probably be less freely employed in future. They are no longer of much use in separating recent and fossil groups of plants and animals, and may even lead to mistakes, because of the extremely frequent use of these terminations in Mineralogy.

= signifies that the preceding word is of the same meaning as that which follows.

α, as a prefix, commonly means without, devoid of, &c.: for euphony it may be followed by *ν*. Thus an‖oplotherium.

ανο, as a prefix, signifies above—*αντι*, against—*ὑπο*, below—*επι*, upon—*μετα* is represented by *trans* in many words borrowed or adapted from Latin—*συν*, together.

ACEPHALOUS. The bivalve mollusca are often thus termed, as being deficient of head. *α* priv., *κεφαλη* head.

ACROGENS. Group of cryptogamic plants; literally, growing from the top. *ακρος* summit, *γινομαι* to be formed.

ACTINOLITE. A mineral not common in plutonic rocks, having a radiated structure. *ακτιν* a ray = radiated hornblende.

AGAMIA. Plants without distinct reproductive organization. *α* priv., *γαμεω* to marry.

ALBITE. One of the varieties or species of felspar. *Albus* white.

ALGÆ. Cellular aquatic plants. *Alga*, sea weed.

ALLUVIUM. Matter transported by currents of water.

AMMONITE. Shell of a cephalopodous mollusk, coiled in a plane spiral, and chambered within, called 'Cornu Ammonis,' from the resemblance of the shell to the horns on the statue of Jupiter Ammon.

AMORPHOUS. Without regular figure. *α* priv., and *μορφη* form.

AMORPHOZOA. The least organized class of the animal kingdom, containing sponges, which are often claimed by the botanists as plants. *α* priv., *μορφη* form, *ζωον* animal.

AMPHIBOLE = Hornblende.

AMPHITHERIUM. An insectivorous quadruped, from the oolite. *αμφι* implying doubt, *θηριον* animal.

AMYGDALOID. A rock produced by fusion, originally vesicular, or full of cavities; when these are filled by spar or other minerals, the rock is named amygdaloid. *αμυγδαλη* almond, *ειδος* form.

ANALCIME. A zoolitic mineral, found in igneous rocks. *α* priv., *αλκιμος* strong, in relation to its feebly electric property.

ANASTOMOZING. Opening into, as vessels uniting by, *αναστομωσις*.

ANGIOSPERMS. Plants whose seeds are encased. *αγγος* a vessel, *σπερμα* seed.

ANNULOSA. One of the classes of the animal kingdom, having ringed or jointed bodies, a double gangliopated nervous cord, and red blood.

ANOPLOTHERIUM. A fossil, pachydermatous quadruped, from the Eocene tertiaries. *α* priv., *οπλον* weapon, *θηριον* animal.

ANTHRACITE. Coal consisting almost wholly of carbon. *ανθραξ* carbon.

ANTHRACOTHERIUM. A fossil pachydermatous animal, found in lignitic tertiaries. *ανθραξ* carbon, *θηριον* animal.

ANTICLINAL. With slopes in opposite directions from an axis. *αντι* against, *κλινω* to incline.

APTERA. A wingless class of insects. *α* and *πτερον* wing.

ARENACEOUS Strata composed of grains like sand. *Arena*, sand.

ARGILLACEOUS. Composed of clay, or containing a notable proportion of clay. *Argilla*, clay.

ARTICULATA. One of the four great divisions of the animal kingdom, including invertebrata with jointed bodies.

ASTEROIDEA. Star fishes. An order of echinodermata, with one opening to the alimentary canal and radiating structure. αστηρ star, ειδος form.

ATOM. An elementary constituent of matter, incapable of further division. α priv., τεμνω to cut.

AUGITE. A mineral very frequent in volcanic lava and ashes, and in basaltic rocks of all ages, also called pyroxene. It is much allied to hornblende. αυγη brightness.

AXIS. The line about which objects are symmetrical, along which they are bent, or around which they turn.

AZOIC (Mur.) The lowest strata devoid of traces of life. α priv., ζωη life.

BACK. Miners' term for joint.

BASALT. A frequent rock of igneous origin, in which prismatic structure is common, the prisms sometimes jointed. The term is borrowed from the *Basaltes* of Pliny.

BASIN. A concave surface of strata; a mass of strata depressed in the centre, or along an axis, by mutual inclination, not by fracture.

BATHYMETRY. Measure of depth in the sea. βαθος depth, μετρον measure. E. Forbes has investigated the bathymetrical distribution of mollusca in the Ægean.

BELEMNITE. The straight shell of a fossil cephalopod; the anterior part chambered, the retral part fibrous, and usually pointed. It was internal. βελεμνον dart, *vulgo* 'thunderbolt.'

BITUMEN. Mineral pitch. Many coals are said to be 'bituminous.' This is not correct: they yield bitumen on being heated, the substance is in fact produced from them by distillation.

BORD. A miner's term for the face of coal parallel to the natural fissures. Contrasted with end.

BOULDER. A large mass of rock, transported by some unusual natural means from a distant situation.

BRACHIOPODA. A class or order of acephalous mollusca, including equivalved and inequivalved groups, with spiral organs on each side of the mouth. βραχιων arm, πους foot.

BRACHYURA. A division of decapod crustacea with short tails. βραχυς short, ουρα tail.

BRANCHIÆ. The breathing organs of animals which respire the air contained in water.

BRANCHIOPODA. A division of crustacea, whose breathing organs are at the base of the organs of motion. βραγχια gills, πους a foot.

BRECCIA. Rock composed of unworn fragments cemented together. The word is Italian, and is matched by the Cumbrian term 'Brockram.'

BRYOZOA. A portion of the delicate productions of the sea once regarded as zoophytes, and now ranked among compound mollusca, receives this name. βρυον moss, ζωα animals.

BUNTER. A German term for the new red sandstone.

CAINOZOIC. The upper division of strata holding recent forms of life. καινος recent, ζωη life.

CALCAIRE GROSSIER. The name of one of the most important of the Eocene tertiaries of France. It signifies coarse limestone.

CALCAREOUS. Of the nature of limestone.

CALLIARD. Local name for hard stone or pebble. χαλις pebble, caillou, *Fr.*, and sometimes galliard.

CANK. Bad, irregular, hard stone.

CARBON. The chemical element of the solid parts of plants, and of coal which is derived from plants, obtained by them from the carbonic acid of the atmosphere.

CARBONIC ACID. One of the constituents of the atmosphere—the aërial food of plants. In rain, spring water, and rivers, it is an important agent of chemical changes.

CARBONIFEROUS. Specially yielding coal.

CATACLYSM. A violent flood, deluge. κατακλυσμος inundation.

CATHEAD. A septarium is so called in the north of England.

CELLULOSÆ. That part of the vegetable world which consists only of a cellular structure, as true sea-weeds, contrasted with Vasculosa, as a tree.

CEPHALA. A great division of mollusca with distinct head. κεφαλη head.

CEPHALOPODA. The most highly organized class of mollusca, with remarkable tentacles round the mouth. The polypus of Homer and Aristotle is an example, now known as the cuttle fish. κεφαλη head, πους foot.

CETACEA. Swimming mammalia, analogous to dolphins and whales. κητος whale. The term is in Homer, but not with the limited meaning now assigned.

CHALK. Properly, a soft white limestone. It is not equivalent to the Latin *calx*, or the German *kalk*, but rather to the Latin *creta* and German *kreide*.

CHERT. A peculiar flinty stone, more or less granular or cellular, occurring in many limestones.

CHLORITE. A mineral often formed in thin plates like mica, and of a greenish hue, whence the name, χλωρος green.

CIRRIPEDA, CIRRIPEDIA. Curl-footed; *cirrus* a whorl, and *pes* foot. A class of articulated animals.

CLAYSTONE = Compact felspar.

CLASS. A principal group of objects in natural history, as Mammalia. It includes orders, families, genera, species, and varieties.

CLEAT. A system of fine parallel fissures in coal, crossing the strata in one direction. A kind of cleavage=leat, nearly =bate.

CLEAVAGE. A fissile structure not coincident with original lamination, an example of metamorphism.

CLINKSTONE. A felspathic igneous rock, which on account of its compactness, is resonant when struck.

CLOUGH. A precipitous rocky glen or steep cliff.

COAL. A mass of plants, greatly compressed, and chemically changed, by slow internal decomposition. According to the degree of change, and the loss of oxygen and hydrogen, the product becomes peat, lignite, jet, caking coal, steam coal, stone coal, anthracite.

COLEOPTERA. An order of sheath-winged insects, including 'Beetles.' κολεος sheath or case, πτερον wing.

CONCHIFERA. A class of acephalous bivalve mollusca, shell bearers. Includes Dimyaria and Monomyaria.

CONCHIFEROUS. Yielding shells, as contrasted with phytiferous, yielding plants.

CONCRETIONARY. A term applied to masses of uncrystallized mineral matter, which have been collected together by molecular attraction.

CONFORMABLE. Strata which are parallel to one another in various positions.

CONGLOMERATE. Rocks resembling consolidated gravel. The pebbles may be wholly or partially cemented.

CONIFERÆ. A great family of gymnosperm vascular plants, including Yews, Pines, Araucaria.

COMPACT. Firm, close-grained stone, as much limestone.

CORNSTONE. Local name for a mottled concretionary limestone in the old red marls.

CORRIE. A glen in the Highlands. *Gael.*

COSMOGONY. The origin of the universe, of the planetary system, or of the earth. κοσμος world, γονη = origin.

COVE. A hollow in rocks.

CRAG. The shelly tertiary deposit of Norfolk, Suffolk, and Essex. *Creggiau.* A shell, in Welsh. A relique of the former British inhabitants.

CRATER. The hollow surrounded by more or less steep edges, at the summit of a volcanic mountain. κρατηρ—*crater*, a cup.

CRINOIDEA. A group of Echinodermata supported on a jointed peduncle. Lily-shaped animals. κρινον a lily, ειδος form.

CROP. The appearance at the surface of a bed of coal or other stratum = Basset.

CRUSTACEA. A class of articulated animals whose external covering is usually firm or crust-like. Includes Decapod, Branchiopod, and other orders. Crabs, Lobsters, Trilobites, &c.

CRUST OF THE EARTH. The mass of rocks known or inferred to exist at and below the surface.

CRYPTOGAMIA. A large division of the vegetable world, in which the reproductive organization is more or less obscure, is not obviously furnished with floral parts, or seeds attached to cotyledons. κρυπτος concealed, γαμεω to marry.

CRYSTAL. A mineral, having regular

geometrical form. Originally the word signified transparency, or similitude to ice. κρυσταλλος ice.

CRYSTALLINE. Confusedly crystallized.

CRYSTALLIZED. Having the structure of a crystal.

CUTTER = Back = Sline.

CYCADEÆ. A group of gymnosperm vascular plants, with stems marked in quincunx by the bases of pinnate leaves. Fruit, a cone.

CYPERACEÆ. Plants like cyperus, sedges. κυπειρος.

DEBACLE. A local deluge or cataclysm.

DELTA. The flat land formed at the mouth of a river, such as that of the Nile described under this name by Herodotus, sometimes triangular in shape, or like the Greek letter Δ.

DELUGE = Cataclysm.

DENSITY. The quantity or weight of matter which exists in a *given space*. In some bodies it is proportioned to pressure. Not = specific gravity.

DENUDATION. The process by which flowing water has removed masses of rocks, and thus uncovered other rocks.

DEOXIDIZED. Deprived of oxygen.

DESICCATION. The art of drying.

DETRITUS. What is removed by natural agencies from the exposed surfaces of rocks.

DIABASE = DIORITE. Plutonic rocks, greenstones, composed of hornblende and felspar.

DIALLAGE. A variable mineral composed of silica, united with magnesia and other bases. Enters into the composition of diallage rock, (gabbro) and serpentine.

DICOTYLEDONOUS. A large division of the vegetable world; with distinct reproductive organs; wood (if any) in concentric layers; leaves with divided nervures; seed with two lobes or cotyledons. δις twice, κοτυληδων seed-lobe = Exogens.

DIDELPHYS. A marsupial quadruped, δις double, δελφυς uterus.

DIKE. A mass of igneous rock, often found traversing other rocks, and sometimes projecting from them, so as to resemble a wall. τειχος = dig, *Gael.*, a wall, fence, or division.

DILUVIUM. The earthy matter accumulated by a deluge.

DINOSAURIA. = DEINOSAURIA. δεινος monstrous, σαυρα lizard.

DIP. The inclination of any stratum, dike, or mineral vein, from a horizontal plane, is expressed by this term. In the case of mineral veins = 'hade,' 'underlay' from the vertical. (See STRIKE).

DIPTERA Insects with only two wings, in the perfect state. δις twice, πτερον wing.

DISTRIBUTION (OF ORGANIC FORMS). E. Forbes treats of this subject under three heads—geological, or in time—geographical, or in space—and bathymetrical, or in depth.

DOLERITE. An igneous rock composed of felspar and augite.

DOLOMITE. A crystallized rock containing carbonate of lime and carbonate of magnesia, often in simple atomic proportion.

DUNE. A sandhill. (Brit.)

ECHINOIDEA. Sea urchins, an order of the class echinodermata. εχινος urchin, ειδος form.

ECHINODERMATA. A large class of radiated invertebrate animals; with firm often crustaceous integument. εχινος urchin, and δερμα skin.

ELVAN. Cornish name for a felspathic rock, occurring in dikes, in the mining districts = Eurite.

ELYTRA. Wing cases of beetles. ελυτρον a sheath.

ENALIOSAURIA. Sea lizards. A fossil group of reptiles including ichthyosaurus and plesiosaurus. εναλιος marine, σαυρα lizard.

END. A miner's term for the face of coal, transverse to the natural fissures.

ENDOGENS. A division of the vegetable world, with distinct reproductive organs, wood in separate bundles, not in concentric layers, leaves mostly with simple nervures, seed with one cotyledon. ενδον within, γινομαι to be formed = monocotyledonous.

ENTOMOSTRACA. A large division of crustacea contrasted with Malacostraca. Literally, shelled insects. εντομον insect, οστρακον shell. The name was first used by Müller.

EOCENE. The lowest great division of the tertiary strata in which the dawn of recent life appears (Lyell.) ηως the dawn, καινος recent.

EOLIAN. Nelson gives this name to loose materials drifted and arranged by the wind.

EPOCH. The point of time when any event happened. εποχη.

ERA = Period.

EREMACAUSIS. Slow chemical change. ηρεμα slowly, καυσις burning.

ESTUARY DEPOSITS. Such are often distinguishable from truly marine and truly fresh water strata.

EURITE = Whitestone = Elvan.

EXOGENS. A division of the vegetable world contrasted with Endogens=dicotyledonous. εξω outside, γινομαι to be formed.

FALSE BEDDING = Oblique stratification.

FALUNS. The shelly beds of Touraine.

FAMILY. Term used in natural history to include some allied genera.

FAULT. A fissure, on one side of which the rocks have been displaced with reference to the other side. The elevation or depression of one side compared to the other may be an inch, foot, 1,000 feet or more.

FAUNA. The animals now or formerly natives in a given tract of land or sea.

FELSPAR. A genus or family of minerals in crystallization, once regarded as a single species, in which silica is combined with various bases. Literally rockspar.

FERRUGINOUS. Obviously containing oxide of iron.

FIRECLAY. Clay which bears a great heat without cracking or melting; often found under beds of coal.

FIRESTONE. Stone which bears moderate heat without injury—usually sandy.

FLAGSTONE. Laminated and fissile stone.

FLORA. The plants now or formerly natives in a given tract of land or sea.

FLÖTZ. The secondary strata were termed flötz or flat-lying by Werner and other German writers.

FORAMINIFERA. A class of minute chambered shells, with an orifice in the plates which separate the chambers. *Foramen*, a small opening.

FORMATION. A group of rocks, associated by geological position, by immediate succession of time, and by organic or mineral affinities.

FOSSIL. Literally, what is dug out, and thus Fossilogy = Orycterology. Technically, often limited to organic remains of ancient life, and thus = Palæontology.

FREESTONE. Stone which admits of being freely cut and shaped; not marked by particular lamination.

GANISTER. Local name of a hard fine grained grit, under a certain coal bed, or a few coal beds in the north of England.

GARNET. A genus or family of minerals in rhomboidal crystallization, composed of silica united with various bases.

GASTEROPODA. A class of mollusca in which the head is developed, and motion is accomplished by means of a muscular foot attached to the lower side of the body. γαστηρ belly, πους foot.

GAULT. An argillaceous member of the cretaceous system, separating the upper and lower green sands.

GEBILDE = German = Terrain = Formation.

GENUS. A group of allied species.

GEOLOGY. Derived from γη earth, and λογος doctrine.

GLACIER, *Fr.*, = Gletscher, *German*. The peculiar ice which moves downward from snowy mountains.

GNEISS. A German miner's term for the oldest group of granitoid strata.

GRANITE. Literally, grain-stone, composed of distinct quartz, felspar, and mica. Sometimes the mica fails, or is partially replaced by hornblende, the rock then passes to syenite.

GREENSTONE. An igneous rock composed of felspar and hornblende.

GREYWACKE = GRAUWACKE. A term once common, now grown obsolete, employed by German miners to designate argillo-arenaceous primary strata.

GRIT. A term of the northern countries for any hard arenaceous rocks. Nearly = sandstone as used in the south of England.

Group. An assemblage of any allied elements.

Gymnosperms (Brong.) Flowering plants with naked seeds; the wood in concentric layers. γυμνος naked, σπερμα seed = gymnogens.

Gypsum. Sulphate of lime. The Greek original γυψος seems to apply also to chalk. γη earth, εψω to boil.

Gyrogonites. The spiral seed vessels of plants (Characeæ) found in fresh water strata. γυρος round, γονος seed.

Hæmatite. Red oxide of iron.

Hazle. A hard, often cherty, gritstone; probably borrowed by the Northumbrians from the German Kiesel—flint.

Hemiptera. An order of insects whose outer wings are half coriaceous. ἡμισυ half, πτερον wing.

Hornblende. A species or genus of minerals, usually dark in colour, of spec. grav. exceeding 3·00, composed of silica united to various bases. In igneous rocks.

Hornstone = Petrosilex = Cornean = Chert. An uncrystallized, infusible, flinty mineral.

Hydrogen. One of the constituents of water. ὑδωρ water, and γινομαι to be formed.

Hydrophytes. Plants which grow under water. ὑδωρ water, φυτον plant.

Hypogene (Lyell.) This term was proposed as a substitute for primary, to mark their formation or transformation from below. ὑπο below, γινομαι to be formed.

Hypozoic. A term proposed in the former edition of this work for the lowest primary strata, such as gneiss, mica, schist, &c., found below all those which contain organic remains. ὑπο below, ζωη life = Azoic (Mur.)

Iceberg. Portions of glaciers broken off and floating on the sea or large lakes.

Ichthyosaur. A fossil marine reptile, with some analogies to fishes. ιχθυς fish, σαυρα lizard.

Igneous Rocks = Pyrogenous rocks. A general term for the mineral aggregates from fusion.

Inclination = Dip.

Inductive Science. That which, founded on observed *facts*, combines these in a manner suited to discover their *causes*.

Infusoria. Minute animal organisms, often obtained by infusing vegetable substances in water.

Invertebrata. Animals without vertebræ. Include mollusca, articulata, and zoophyta.

Ironstone. Carbonate of iron, usually combined with argillaceous matter, in a nodular form.

Isocheimal. Lines or surfaces in which the mean winter temperatures are equal. ισος equal, χειμα winter.

Isotheral. Lines or surfaces in which the mean summer temperatures are equal. ισος equal, θερος summer.

Isothermal. Lines or surfaces in which the temperatures, as indicated by thermometers, are equal. ισος equal, θερμη heat. This equality may be determined for days, months, or years; commonly used for mean annual equality.

Joint. A fissure in rocks.

Kaolin. China clay, arising from decomposed felspar.

Lacustrine. Produced by, or belonging to, lakes.

Laminated Rocks, are such as are divided, or divisible, into thin parallel layers or laminæ.

Lepidodendron. A remarkable genus of fossil plants, characteristic of the upper Palæozoic strata, λεπις scale, δενδρον wood.

Leucite. A characteristic mineral in certain lavas, usually of a white colour. λευκος white.

Leucostine. A light coloured lava. λευκος white.

Lias. The thin bedded limestone at the base of the oolitic series in Somersetshire = layers = lyers.

Lignite. Fossil wood carbonized.

Limestone. Indurated carbonate of lime. Often of organic origin.

Lithophyta. Marine plants whose skeleton is formed by secretion of calcareous matter instead of carbon.

Loam. Soil or subsoil in which sand and clay are combined.

Lusus Naturæ. A term of the 16th and 17th centuries for several tribes of organic remains.

Lycopodiaceæ. A natural family of flowerless plants, ranking with ferns among vascular cryptogamia.

Macigno. An Italian rock of the secondary period.

Magnesian Limestone = Permian = Dolomite.

Mammalia. Vertebrated animals of the highest grade of organization; which suckle the young = Saugethier = Mammiferes. *Mamma*, the breast.

Mammoth. The fossil elephant of Russia.

Marble. Stone capable of polish, usually limestone.

Marl. Properly an argillaceous stratum with much calcareous matter in it. The term is variously employed. In Norfolk soft chalk is called marl, in Worcestershire the 'red marl' contains very little calcareous matter. In Ireland, fresh water clays rich in shells are called marl.

Marsupialia. A division of mammalia, with external pouch, in which the development of the young is completed. *Marsupium*, a pouch.

Mass. In astronomy the whole quantity of matter in a given body or group of bodies, as the sun, Jupiter with his moons, &c.

Mastodon. The great fossil mammal of North America, received this name from the conical or teat-like elevations on its teeth. μαστος teat, οδους or οδων tooth.

Megalosaur. The great fossil land lizard of Stonesfield. μεγας great, σαυρα lizard.

Megathere. A great fossil quadruped of South America. μεγας great, θηριον animal.

Meiocene. The middle tertiaries thus termed by Lyell, as holding a less proportion of recent species than the pleiocene. μειων less, καινος recent.

Mesotype. A zeolitic mineral frequent in cavities of basalt and lava. μεσος middle, τυπος type.

Mesozoic. The great division of the strata holding the middle forms of life. μεσος middle, ζωη life.

Metamorphism. The change effected by heat in previously consolidated rocks. Literally, transformation. μετα trans, μορφη form.

Mica. A genus of minerals mostly remarkable for the thin brilliant elastic plates into which it is divisible. *Mico*, to shine.

Millstone Grit derives its name from its use.

Mineral. Inorganic matter obtained from the earth.

Molasse. A series of tertiary rocks in Switzerland.

Mollusca. A great division of invertebrata. Literally, soft animals. *Mollis*, soft = Malacozoa.

Monocotyledons. Flowering plants with one seed lobe; wood in bundles, leaves mostly with simple nervures. μονος one, κοτυληδων lobe.

Moraine. A Swiss term for the heaps of detritus transported by glaciers.

Moya. Mud thrown out by volcanoes in South America.

Mudstone. Local name for the Ludlow Rocks.

Muschelkalk. Literally, shell limestone; a member of the German and French Trias, not yet known in England.

Nagelflue. A conglomeritic tertiary rock of Switzerland.

Neocomian System = Lower green sand, according to most English geologists *sed quære*.

Neptunian. The stratified deposits generally are often thus termed in contradistinction to the plutonic rocks.

New Red = Lower Mesozoic strata = Trias of Germany = Saliferous system.

Nitrogen. One of the constituents of the atmosphere.

Nodule. A mass of rock collected by attraction round some central point or nucleus.

Nucleus. The central part of some mineral or organic body.

Nummulites. A group of chambered spiral univalves.

Obsidian. A glassy volcanic product.

Ochre. Silica and alumina in very fine powder, coloured by oxide of iron.

Old Red = Devonian wholly or in part. A palæozoic system of strata.

Oligoclase. A variety or species of felspar.

Olivine. A mineral composed of silica with magnesia and other bases, frequent in igneous rocks.

Oolite. Limestone formed of spherical or ellipsoidal masses, like small eggs, collected round shells or portions of organic matter. ωον egg, λιθος stone.

Ophidia. The class of reptiles which includes serpents. οφις serpent.

Organic Remains. Any recognizable parts of plants or animals in a fossil state.

Orthoceras. Chambered shell of a cephalopod mollusk, usually straight. ορθος straight, κερας horn.

Orthoclase. A variety or species of felspar containing potash. ορθος straight, κλασις fracture.

Order. The first subdivision of a class in natural history.

Outliers. Parts of any stratum which lie detached and separated from the main body, usually the effect of denudation.

Oxygen. One of the constituents of air, water, and most rocks and minerals—'vital air.' Literally, source of sharpness or acidity. οξυς sharp, and γεν for origin.

Pachydermata. An order of mammalia frequent in tertiary strata. Includes elephant, rhinoceros, mastodon, &c. παχυς thick, δερμα skin.

Palæontology. Zoology and botany, applied to the ancient forms of life preserved on the earth. παλαιος ancient, ων-οντος being, λογος doctrine.

Palæotherium. An extinct pachyderm from the Eocene tertiaries. παλαιος ancient, θηριον animal.

Palæozoic. The lowest of three grand divisions of strata, including the most ancient forms of life. παλαιος ancient, ζωη life.

Pegmatite. Binary granite containing only quartz and felspar.

Pelagian. Formed in deep sea, as distinct from littoral, and estuary.

Pelorosaur. The great reptile of the Wealden. πελωρος gigantic, σαυρα lizard.

Period. The measure of time which has elapsed between two events = duration.

Peroxide. The full degree of oxidation.

Petrifaction. Conversion to stone. The term is not confined to fossils.

Phænomena. Things appearing. Facts observed frequently.

Phanerogamia. Flowering plants with distinct reproductive organs. φανερος apparent, γαμεω to marry.

Phascolotherium. A marsupial quadruped from the oolite. φασκωλος bag, θηριον animal.

Phœnogamic = Phanerogamic.

Phonolite = Clinkstone.

Physical Science. The knowledge of nature, the branches of human study intended to augment this knowledge. φυσις nature; in a limited sense = natural philosophy, so as to exclude natural history.

Phytiferous. Yielding plants.

Pitchstone. A glassy igneous rock, chemically related to felspar.

Planerkalkstein. A German rock of the upper mesozoic era.

Plagimyona, with lateral muscles; nearly = Dimyaria. πλαγιος oblique, μυων muscle.

Pleiocene. The upper tertiaries so called by Lyell, as containing the larger proportion of recent species of plants and animals. πλειων more, καινος recent.

Plesiosaur. A marine fossil reptile, more allied to lizards than was the ichthyosaur. πλησιος near to, σαυρα lizard.

Pliosaur. The great reptile of the Kimmeridge clay. πλειων more, σαυρα lizard.

Plutonic Rocks. Igneous products at some depth below the surface of the land or sea, 'unerupted lavas.'

Porphyry. An igneous rock with detached crystals, mostly of felspar, often red. πορφυρεος purple.

Potstone. A soft magnesian rock.

Pozzulana. Volcanic ashes, more or less cemented together = trass = tephrine.

Precipitates. Deposits occasioned by chemical decomposition; matter separated from solution.

Primarized. Altered so as to resemble primary rocks.

PRIMITIVE, as applied to rocks, was meant to include the earliest of all, but was often misapplied, and is now seldom used.

PRIMORDIAL. Of the earliest period. Barrande uses the term. = Cambrian of this treatise.

PROTEROSAUR. A Saurian fossil of the προτερος earlier or before, σαυρα lizard.

PROTOGINE. The peculiar foliated granitic rock of Mont Blanc, is unfortunately thus named. It is far from being of the first antiquity. πρωτος first, γινομαι to be formed.

PROTOXIDE. The first degree of oxidation.

PROTOZOIC. The strata containing the earliest of the forms of life; the supposed first series of animals and plants. πρωτος first, ζωη life = primordial.

PTERODACTYL. A flying lizard of the mesozoic period, with one elongated wing finger. πτερον wing, δακτυλος finger.

PUDDINGSTONE = Conglomerate. That of Hertfordshire contains flint pebbles, in a siliceous cement.

PUMICE. Volcanic matter, expanded from a glassy state into a spongy or frothy state, by extrication of gas or steam.

PYRITES. Iron, copper, &c., combined with sulphur. The most ordinary species is iron pyrites, which is so hard as to strike fire. πυρ fire, and the termination *ites*, for λιθος.

QUADERSANDSTEIN. In Saxony = the lower green sand formation.

QUADRUMANA. An order of mammalia, including monkeys and lemurs. Literally, four-handed.

QUARTZ. Crystallized silica; rock crystal, a term borrowed from German miners.

QUARTZITE. Sandstone or gritstone much indurated by heat, or pressure, or silicated solution. Thus, rolled grains of quartz and felspar, often become firmly cemented and even confluent at the edges.

RACE. An allied group. The term induces the idea of successive transmission.

RADIARIA. A class in Lamarck's system of Invertebrata, including echinodermata, acalephida, &c.

RED MARL = Keuper = Marnes irisees = Poikilitic Marls.

ROCK SALT = Chloride of Sodium.

ROTTENSTONE. The siliceous and aluminous residue of impure limestone which has been subject to dissolution by acids.

RUBBLE. The loose upper covering of many rocks = head = fay.

RUMINANTIA. Mammalia which chew the cud and have a divided hoof, as deer, ox.

SALTS. Combination of acids and bases.

SANDSTONE = Arenaceous rocks = Gritstone. Composed of sand, usually quartz sand.

SAURIAN. Fossil reptiles analogous to lizards. σαυρα lizard, as Enaliosaurian, Deinosaurian, &c.

SCAR. A bold precipice of rock.

SCHAALSTEIN, *Germ.* Stratified stone partly of a volcanic origin, allied to Tephrite.

SCHIST. Fossil rocks; laminated rocks. σχιζω to divide = schistus. Should not be regarded as synonymous with slate.

SCHORL. A frequent mineral in Cornwall, an ingredient of the rock called Cockle = Tourmaline.

SCORIÆ = Cinders.

SEAMS = Beds or thin strata, as seams or beds (and in Somersetshire, veins) of coal.

SECONDARY STRATA = Mesozoic Strata. The second or middle great group of strata.

SECTION. A face of rocks exposed by nature or art, or represented in a drawing.

SEDIMENTS. Earthy deposits from mechanical suspension in water.

SELENITE. Crystallized sulphate of lime, literally moonstone. σεληνη moon, with *ites*.

SELFSTONE. Blocks of stone lying detached at, or not far below, the surface. A north of England term sometimes applied to solitary boulders = 'earth-fast.'

SEPTARIA. Nodules divided by fissures, which are usually filled with plates of

spar and other minerals. These plates are sometimes confined to the interior. Septum a fence. = Ludus Helmontii.

Series. Any group of allied objects arranged in sequence, or supposed to have such affinity.

Serpentine. A beautiful rock, composed of some magnesian mineral, as diallage, and felspar; spotted like a serpent.

Shale. A German term for laminated argillaceous strata.

Shingle. Loose pebbles on the sea shore.

Silica. The most frequent constituent of minerals and rocks; an earth compound of silicium and oxygen. It acts as an acid, making numerous combinations with bases called silicates, bisilicates, trisilicates.

Silt. Fine sediment from rivers, &c.

Slate. A fissile argillaceous rock, whose lamination is not due to deposition as in shale, but is a subsequent effect of metamorphism called cleavage.

Sline = Back.

Species. The fundamental idea of permanent form and nature in created beings. Supposed to originate in one individual or in a pair, and to be variable within known or discoverable limits.

Spherical (oblate.) A globe compressed at the poles.

Spores. The reproductive germ of cryptogamic plants. σπορα seed.

Stalactite. Earthy matter separated from solution in water, and consolidated while falling, so as to be attached to the rock above, as calcedony in Cornwall, sulphate of barytes in Derbyshire, carbonate of lime very frequently. σταλαζω to drop.

Stalagmite. The same matter as that which forms stalactite receives this name when the drop reaches the floor before parting with the mineral substance. σταλαγμα a drop.

Steatite. A soft smooth magnesian rock. στεαρ fat.

Stilbite. A zeolitic mineral with brilliant surface, found in volcanic and trap rock. στιλβω to shine.

Strata. Rocks successively deposited from water; the several beds or layers of thin rocks.

Strike. The direction of a line drawn horizontally on a sloping plane surface, whether, as most usually, on the bed surface of stratification, or on the plane of a joint, or a plane of cleavage. The dip of any plane is at right angles to the strike.

Syenite. An igneous crystallized rock, composed of quartz, felspar, and hornblende; named from Syene, on the Nile in Egypt, whence much was anciently quarried.

Synclinal. Dipping toward an axis. συν together, κλινω to incline.

System. A group having such relations as to require to be classed together. συν together, ιστημι to stand. A method of classification.

Talc. A soft flexible magnesian mineral otherwise resembling mica.

Talus. The loose detritus accumulated by falling from the face of rocks and precipices. The angle of slope of a talus is seldom so great as 30° from the horizon.

Terrain = Formation = Gebilde.

Tertiary. The third or upper grand division of strata = Cainozoic.

Theory. A general contemplation or combination of many separately ascertained truths. θεωρια.

Thylacotherium. θυλακος pouch, θηριον animal = Amphitherium.

Tilestone = Flagstone.

Toadstone = Todtstein = Deadstone, from its being unfruitful of lead ore in the mining district of Derbyshire.

Topaz. The gem. A mineral ingredient in some granites, &c.

Trachyte. A porous felspathic rock frequent in Auvergne and other volcanic countries of Europe. τραχυς rough.

Transition. The passage from one condition or group to another. Formerly applied to the palæozoic strata or some of them.

Trap. Any plutonic rock with the exception of granite, is often described as of the Trap Family. The term is neither exact nor convenient. Trappa, *Swed.*, treppe, *Ger.*, step formed.

Travestin. Limestone formed from fresh water = calcareous tufa.

Tribe. A group of natural objects.

Trilobites. An extinct family of crustacea. Three-lobed fossils. τρεις three, λοβος a lobe.

Tripoli. A polishing powder, formed of the siliceous shield of infusoria and diatomaceæ.

Tufa = Calcareous travestin; volcanic = Tuff.

Tuff. Coherent scoriæ and ashes from a volcano.

Tunicata. A class of acephalous mollusca, rarely found fossil.

Unconformable. Strata laid on one another or against one another, having different dipping at different angles, or in different directions.

Variety. A subdivision of species founded in characters supposed to be not permanent.

Vasculosa. Plants in whose tissue are vessels as well as cells.

Vein. A fissure in a rock filled by mineral or metallic matters of a different nature, as mineral veins, or consolidated in a different way, as some veins in granite, and other igneous rocks.

Volcanic. Implying the action of fire apparent at the surface, and thus contrasted with plutonic, which marks underground phenomena.

Wacke. An earthy variety of plutonic rocks, bearing to basalt nearly the same relation which volcanic bears to the more crystallized and solid kinds of volcanic rocks.

Warp. Silt.

Whin = Basalt. (Also locally used for any *hard* rock.)

Zeolite. A genus or family of minerals, which contain water, and on this account intumesce under the blowpipe. Mostly become gelatinous in mineral acids. ζεω to boil, λιθος.

Zoophaga. A division of gasteropodous mollusks with canal or notch at the base of the aperture and carnivorous habits = Siphonostomata. ζωον animal, φαγω to eat.

Zoophyta. Plant-like animals. A great division of invertebrata, the fourth and lowest division of the animal kingdom. ζωον animal, φυτον plant.

INDEX.

[*For Index of Authors, see p.* 668.]

INDEX OF AUTHORS

QUOTED OR NAMED.

GLASGOW:
PRINTED BY BELL AND BAIN.

NEW WORKS

PUBLISHED BY

RICHARD GRIFFIN & COMPANY,

PUBLISHERS TO THE UNIVERSITY OF GLASGOW,

5 Warwick Square,	**Prince of Wales Buildings,**
PATERNOSTER ROW,	BUCHANAN STREET,
LONDON.	GLASGOW.

WORKS BY LORD BROUGHAM.

I.

ERRATA OBSERVED.

Page 48, line 15, *for* 'siberian' *read* 'silurian.'
" 101, " 6, *for* 'comprise' *read* 'compose.'
" 102, the asterisk applies to Skiddaw Slate.
" 104, line 1, *for* 'agnostas' *read* 'agnostus.'
" 250, last line (note), *for* 'transfixed' *read* 'transferred.'
" 441, *for* 'Mammoth' *read* 'Mastodon.'

Literary Periodicals, 3 vols.

"What a marvellous variety of study and argument; what a faculty must there be for readily abstracting the mind from one subject and concentrating it upon another! And yet, contrary to the vulgar opinion, that one man can only excel in one thing, how well is all here done. Whether it be biography, history, oratory, or science, it is the best of its kind; every page sparkles with profound thought and original conception. Lord Brougham is never dull or prosy, whether discoursing of philosophy or politics. In his hands science is amusing, because he treats it familiarly, and is content to discourse in plain English when he addresses himself to an English audience. His biographies have a peculiar interest; for he was personally acquainted with many of the distinguished men whose lives he narrates, and he introduces characteristic anecdotes that give a better knowledge of the person than the most elaborate description."—*Critic.*

II.

CONTRIBUTIONS TO THE EDINBURGH REVIEW—Political, Historical, and Miscellaneous, *now first collected*, 3 vols. 8vo, *in preparation.*

III.

PALEY'S NATURAL THEOLOGY, with Notes and Dissertations by Lord Brougham and Sir Charles Bell, new edition, 3 vols. small 8vo, 7s. 6d.

"When Lord Brougham's eloquence in the Senate shall have passed away, and his services as a Statesman shall exist only in the free institutions which they have helped to secure, his Discourses on Natural Theology will continue to inculcate imperishable truths, and fit the mind for the higher revelations which these truths are destined to foreshadow and confirm."—*Edinburgh Review.*

SCIENTIFIC MANUALS.

Botany.

MANUAL OF BOTANY; an Introduction to the Study of the Structure, Physiology, and Classification of Plants. By JOHN H. BALFOUR, F.R.S.E., Professor of Botany in the University of Edinburgh. Numerous Illustrations. Third Edition, revised by JOS. WILLIAMS, M.D., Lecturer on Botany, Original School of Medicine, Dublin. Crown 8vo, 10s. 6d.

Dyeing.

MANUAL OF DYEING, Practical and Theoretical. By JAMES NAPIER, F.C.S. With Engravings. Post 8vo, 7s. 6d. cloth.

Electro-Metallurgy.

MANUAL OF ELECTRO-METALLURGY; containing an Account of the most Improved Methods of Depositing Copper, Silver, Gold, and other metals. With numerous Illustrations. By JAMES NAPIER, F.C.S. Second edition, revised and enlarged. Crown 8vo, 3s. 6d. cloth.

Geology.

MANUAL OF GEOLOGY; Practical and Theoretical. By JOHN PHILLIPS, M.A., F.R.S., F.G.S., Deputy Reader in Geology in the University of Oxford. Numerous Engravings. Crown 8vo, 12s. 6d. cloth.

Mental Science.

MANUAL OF MENTAL SCIENCE. SAMUEL TAYLOR COLERIDGE ON METHOD; ARCHBISHOP WHATELY'S TREATISES ON LOGIC and RHETORIC. In One Vol., forming a Section of the Encyclopædia Metropolitana. Crown 8vo, 5s. cloth.

Metallurgy.

MANUAL OF METALLURGY: Being an Account of Assaying, Mining, Smelting, &c. By J. A. PHILLIPS, F.C.S. Second edition, corrected. With above 200 Engravings. Crown 8vo, 12s. 6d. cloth.

Natural and Physical Sciences.

BOOK OF NATURE; a Comprehensive Introduction to the Natural and Physical Sciences. From the German of Professor Schoedler, with numerous additions. By HENRY MEDLOCK, F.C.S. Second edition, corrected and enlarged. With Copious Index, and 500 Engravings. Post 8vo, 7s. 6d. cloth.

Photography.

MANUAL OF PHOTOGRAPHY, embracing the Daguerreotype, Calotype, and all the published Photographic processes. By ROBERT HUNT, F.R.S., Professor of Physical Science in the Museum of Practical Geology. Fourth edition, enlarged. With numerous Engravings. Crown 8vo, 6s. cloth.

Political Economy.

POLITICAL ECONOMY; A Treatise on the Science which Treats of the Nature, Production, and Distribution of Wealth. By NASSAU W. SENIOR, late Professor of Political Economy, Oxford. Third edition. Crown 8vo, 4s. cloth.

Steam-Engine.

MANUAL OF THE STEAM-ENGINE; including its History and Applications to Locomotion, Navigation, Mining, and Manufactures. By WILLIAM FERGUSON, F.C.S. Numerous Engravings. Crown 8vo.—*In preparation.*

Trigonometry.

A TREATISE ON TRIGONOMETRY. By GEORGE B. AIRY, F.R.S., Astronomer Royal. New Edition. Edited by HUGH BLACKBURN, M.A., Professor of Mathematics in the University of Glasgow. Crown 8vo, 2s. 6d. cloth.

Veterinary Art.

PRACTICAL TREATISE ON THE DISEASES OF THE HORSE. By W. C. SPOONER, Esq. With 50 Engravings. Crown 8vo. 3s. cloth.

[illegible]

HISTORY OF [illegible]. [illegible]

HISTORY OF THE DECLINE AND FALL OF THE ROMAN EMPIRE. [illegible]

HISTORY OF GREEK AND ROMAN PHILOSOPHY [illegible]

[illegible] AND METAPHYSICAL PHILOSOPHY. THE [illegible] [illegible]

HISTORY OF THE [illegible] [illegible]

[illegible]

[illegible] OF THE [illegible] [illegible]

[illegible] By JOHN PHILLIPS, M.A., F.R.S. [illegible]

Volumes in Active Preparation.

I.

[illegible] By [illegible] F.R.S., [illegible]

II.

[illegible]

III.

[illegible] HISTORY, from the [illegible] Century. By [illegible]

IV.

ECCLESIASTICAL HISTORY. [illegible]

V.

[illegible]; or, The Historical [illegible] of Languages. [illegible]

VI.

MORAL AND METAPHYSICAL PHILOSOPHY.—THE [illegible] AGES. [illegible]

VII.

MORAL AND METAPHYSICAL PHILOSOPHY.—MODERN [illegible] By [illegible]

VIII.

PRINCIPLES AND PRACTICE OF MEDICINE. By [illegible]

[illegible]

hed.

HIS ... OLD, D.D.,
l

HIS ... POWER.
B

HIS ... NCE. By
t ... IEWELL, and
o
"A ... long time."—
Critic.

MOI ... OPHY OF
T

HIS ... he GREEK
E ... MES M'CON-
E

TRI ... l. Edited
b ... gow.

COM ... Traditions
a ... of Historical
S ... butors.

GEO ... A., F.R.S.,
F ... Illustrations.

SCU ... Numerous
I

THE ... , Naviga-
ti ... ous Illustra-
ti

ECC ... tury. By
E

ECC ... esent Day.
E

GLC ... SIR JOHN
S

MOI ... E AGES.
I

VII.

MORAL AND METAPHYSICAL PHILOSOPHY—MODERN PHILOSOPHY. By Rev. F. D. MAURICE, M.A., Chaplain of Lincoln's Inn.

VIII.

PRINCIPLES AND PRACTICE OF MEDICINE. By R. WILLIAMS, M.D., Physician to St. Thomas's Hospital, London, and W. AITKEN, M.D., Demonstrator of Anatomy in the University of Glasgow.

IX.

ARITHMETIC. By Rev. DR. PEACOCK, Dean of Ely. Revised.

GRIFFIN'S PORTABLE CYCLOPÆDIAS,

A Series of Reference Books,

ADAPTED TO THE WANTS OF THE PRESENT AGE,

EMBRACING BIOGRAPHY, GEOGRAPHY, HISTORY, RELIGION, THE NATURAL AND PHYSICAL SCIENCES, &c.

Handsomely printed in 8vo, and profusely Illustrated.

BIBLICAL CYCLOPÆDIA; or, Complete Dictionary of Eastern Antiquities, Geography, Natural History, Sacred Annals and Biography, Theology, and Biblical Literature. By the Rev. JOHN EADIE, D.D., LL.D., Professor of Biblical Literature to the United Presbyterian Church. With Numerous Illustrations. Fifth Edition, revised, 7s. 6d.

"This first-rate Biblical Cyclopædia."—*M'Phail.*
"A publication of extraordinary merit."—*British Banner.*
"The best dictionary of the kind we have yet seen."—*Nonconformist.*

CYCLOPÆDIA OF CHEMISTRY: including the Ap[illegible]n of the Science to the ARTS, MINERALOGY, and PHYSIOLOGY. By ROBERT D[illegible]OMSON, M.D., F.R.S., F.R.S.E., F.C.S., &c., Professor of Chemistry at St. Thomas'[illegible]lege, London. With Numerous Illustrations, 12s. 6d.

"Its limited compass—its completeness and correctness[illegible] Cyclopædia of Chemistry to all who feel an interest in the science."—*Athen*[illegible]
"In every respect worthy of praise. It is within a[illegible]e best compendium of Chemistry which we have yet seen."—*Lancet.*
"A practical publication in the highest degree valu[illegible]*l.*
"Contains a comprehensive summary of Chemical[illegible]rm most useful for reference and suitable for study."—*Literary Gazette.*

CYCLOPÆDIA OF UNIVERSAL BIO[illegible] Series of Original Memoirs of the most remarkable [illegible] Nations. By SIR ARCHIBALD ALISON, D.C.L.; JOHN HI[illegible]ASY, M.A.; PROFESSOR FERGUSON, A.M.; E. RICH, ESQ[illegible]ESSOR EADIE, D.D., LL.D.; JAMES HEDDERWICK, ESQ.[illegible] KNIGHT, ESQ.; PROFESSOR SPALDING, M.A.; W. BA[illegible]TER, F.R.S.; JAMES BRYCE, ESQ., F.G.S.; PROFESSO[illegible]LL.D.; R. D. THOMSON, M.D., F.R.S.; JA[illegible]S MANSON, ESQ.; and RALPH N. WORNUM[illegible]c. &c. 12s. 6d.

"A wonderful insta[illegible]—*Critic.*
"This work diffe[illegible] remarkable features;—the great number of [illegible]ndeed celebrity of the writers engaged, and th[illegible]ces. The first, and for purposes of reference t[illegible] noticed: this is managed by very brief accou[illegible]y little more than lists with the date of birth a[illegible], which procures the subject a place. The men[illegible]nd celebrated, as may be seen from the enumerati[illegible] class of lives with which his studies have made him most familiar. Alison and Creasy, for example, undertake naval and military men. This distribution gives a striking and novel peculiarity to the lives of prominent men, however short. It gets rid of mere dry compilation. The writers take a whole view of the life and character of their subjects, and present a judgment on both, instead of a bare recital of facts with an echo of opinions so old as to be commonplace. The scale is well preserved."—*Spectator.*
"No English work of the kind can stand a comparison with the present one."—*Manchester Advertiser.*
"With those articles to which we have turned in order to test the book we are highly satisfied."—*Literary Gazette.*
"The *ne plus ultra* of biographical dictionaries."—*Glasgow Herald.*

CYCLOPÆDIA OF HISTORY: a Complete Series of Chronological Tables, from the Beginning of the World to the Present Time, on a New Plan, comprehending an arrangement according to dates and an Alphabetical arrangement. Edited by I. M'BURNEY, B.A., and SAMUEL NEIL, ESQ. 10s. 6d.

"A storehouse of Facts and Dates."—*Spectator.*
"Admirably adapted as a book of reference. . . . Altogether a comprehensive and complete outline of Universal History."—*Literary Gazette.*
"Most useful and convenient. . . . One of those which no gentleman's library should be without."—*Edinburgh Guardian.*
"Its importance and value cannot be overestimated."—*Glasgow Herald.*

Volumes in Active Preparation.

UNIVERSAL GAZETTEER; or Cyclopædia of Political and Physical Geography, with Pronunciation, and numerous Illustrations. By JAMES BRYCE, A.M., F.G.S.

ANALYTICAL CONCORDANCE TO THE HOLY SCRIPTURES, with the Text in full. By the Rev. PROFESSOR EADIE, D.D., LL.D.

Encyclopaedia Metropolitana

Second Division

Applied Sciences

12s. 6d.